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INFLUENCE OF WEATHER CONDITIONS ON THE NITROGEN CONTENT OF WHEAT—II[1]

BY J. W. HOPKINS[2]

Abstract

Supplementing a previous statistical study, coefficients designed to weight observed temperatures in proportion to their assumed effect on respiration were computed from the daily observations for three 3-week periods extending from July 1 to September 1. After allowing for the effect of May and June rainfall there was a moderate but significant partial correlation ($r = +0.33$) between nitrogen content and the sum of the temperature coefficients for the last two periods.

There was a positive correlation ($r = +0.74$) between height of crop and yield of grain, and a negative correlation ($r = -0.50$) between height and nitrogen content. The partial correlation between nitrogen content and yield, after eliminating variations in both associated with height, was negligible ($r = -0.07$), suggesting that reductions in yield due to restriction of the later stages of translocation did not result in significant modification of the nitrogen content of the grain.

Results of the investigation as a whole are briefly discussed.

Introduction

It was at one time thought that the greater part of the nitrogenous constituents of cereal grains was laid down during the earlier stages of kernel formation, subsequent "filling" resulting largely from the translocation of carbohydrates. Retardation or inhibition of this latter process by, for example, drought or hot weather would thus obviously affect the composition of the matured grain.

Chemical studies by Brenchley and Hall (2), Thatcher (8, 9), Woodman and Engledow (11) and more recently by McCalla and Newton (5) have not, however, supported this view. The last-mentioned authors also point out that analytical methods employed by some of the earlier workers may have led to fictitiously high estimates of nitrogen content during the initial stages of kernel formation, and it now appears that although the pericarp tissue may be somewhat richer in nitrogen than the subsequently developed endosperm, the carbon/nitrogen ratio of the translocated material is much less variable than was previously supposed. It might be expected therefore that weather conditions would operate to modify the composition of the crop largely

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through their effect on the vegetative production of carbohydrates and protein and on the rate of respiration in the developing grain, rather than on the progress of translocation.

The respiratory effect has been studied by McGinnis and Taylor (6). These writers conclude that although differences in the amount of respiration were definitely incapable of accounting for the whole of the observed variation, they might modify appreciably the percentage nitrogen content of wheat, oats or barley.

Agricultural meteorological studies by the author (3), employing the statistical method, indicated that whereas the yield of wheat grown annually at points in Saskatchewan and Alberta was significantly affected by the amounts of rain falling in May, June and July, the only significant influence of rainfall on nitrogen content was exerted during May and June, a finding which is consistent with the chemical results previously mentioned (2, 5, 8, 9, 11). They did not, however, establish any relation between nitrogen content and the temperature conditions prevailing in July and August, although hot weather at this time might certainly be expected to accelerate respiration.

It was felt that the monthly averages of daily maximum and minimum readings employed perhaps failed to provide a suitable measure of the temperature conditions experienced by the crop, with the result that real effects escaped detection. The outcome of a further analysis, designed to weight the observed temperatures in proportion to their assumed physiological effect (1), is now described. Opportunity is also taken to present the results of a few additional calculations relating growth, yield and nitrogen content.

Physiological Temperature Summations

According to Lundegårdh (4), the respiration of such plant parts (seedlings and foliage leaves) as have been studied at a series of temperatures increases in an approximately exponential manner with temperature up to the lethal point, the results indicating temperature quotients of from 2 to 3. It seemed desirable therefore to ascertain whether there was any correlation between nitrogen content and an exponential function of the temperature, designed to weight the observed values in accordance with this fact.

The actual temperature quotient of the respiration of developing wheat kernels being unknown, the arbitrary value 2.0 was employed. This may have been somewhat conservative. Adopting this value, the assumed respiration at any temperature $t°$ F. will be in the proportion of $2^{\frac{t-32}{18}}$ to that at 0° C. Substitution of the maximum and minimum temperatures recorded on any day in this expression yielded maximum and minimum temperature coefficients, which were summed to give a daily temperature coefficient. These daily sums were then averaged over three 3-week periods, namely July 1–21, July 22–August 11, and August 12–September 1. The average values thus obtained at each station in each season for which crop data were available are shown in Table I, and provided three variables whose relation to nitrogen content was to be investigated.

TABLE I

TEMPERATURE COEFFICIENTS

Station	Year	July 1–21	July 22–Aug. 11	Aug. 12–Sept. 1	Station	Year	July 1–21	July 22–Aug. 11	Aug. 12–Sept. 1
Lacombe, Alberta	1915	5.48	7.97	7.59	Indian Head, Saskatchewan	1928	7.76	8.52	6.11
	17	8.10	6.36	6.98		29	8.83	10.14	9.58
	21	7.32	7.49	6.83		31	8.23	9.87	9.10
	22	7.65	7.91	7.14		32	8.22	9.72	7.66
	25	8.62	8.12	6.22					
	28	6.96	8.12	5.26	Scott, Saskatchewan	1915	6.23	8.37	8.38
	30	8.28	8.01	7.29		17	9.28	7.72	7.35
	31	6.71	7.24	7.12		18	8.57	8.04	6.94
	32	6.18	8.12	7.11		21	8.36	7.37	7.72
						23	7.88	6.09	6.94
Lethbridge, Alberta	1915	6.23	8.29	8.77		24	8.80	6.40	6.34
	16	7.89	6.98	7.02		25	7.91	8.25	6.69
	17	9.44	7.87	7.95		26	7.71	7.28	6.75
	21	8.26	8.04	7.92		29	7.61	8.70	8.54
	22	7.58	8.48	7.92		30	7.57	7.85	7.67
	25	8.83	7.91	6.74		31	6.98	7.64	7.99
	26	9.05	8.02	6.93		32	6.38	8.80	7.33
	27	6.82	6.62	7.72					
	28	6.60	8.83	5.96	Rosthern, Saskatchewan	1915	6.14	8.20	7.82
	29	8.13	9.41	9.49		21	7.90	7.32	7.87
	30	8.58	9.21	8.13		22	7.71	9.26	7.49
	31	7.58	8.98	9.13		24	8.95	6.75	6.49
	32	7.60	9.61	7.29		25	8.20	8.87	6.96
						26	8.51	7.86	7.05
Indian Head, Saskatchewan	1915	6.31	8.65	7.90		27	7.32	7.42	7.93
	18	8.35	7.30	6.63		28	7.97	8.62	5.70
	24	8.54	6.65	6.45		29	8.34	7.54	8.48
	25	8.74	9.11	6.67		30	8.51	8.28	8.51
	26	9.13	8.09	7.86		32	7.16	8.63	7.47

Relation between Temperature Coefficients and Nitrogen Content

A preliminary study of the relation was made by determining the regression of nitrogen content on the temperature coefficient for each period independently, *i.e.*, neglecting in each case any associated effect of temperature in the two other periods. As a significant correlation between nitrogen content and May and June rainfall had already been demonstrated (3), it was necessary to determine the partial regression of nitrogen content on the temperature coefficient after allowing for the association of both with the rainfall during these months. The nitrogen content of the various harvests and the amounts of rain recorded will be found in Tables I and II of the author's earlier paper on this subject (3), and the method of calculation of the seasonal variance of the observed quantities about the means for the different stations is indicated in Section 3 of that paper.

Calculation of the necessary sums of squares and products gave the following normal equations in b_0 and b_1, the partial regression coefficients of nitrogen content on May and June rainfall and on the temperature coefficient for the period July 1–21, respectively:

$$196.8993b_0 - 47.0706b_1 = -13.3427$$
$$-47.0706b_0 + 40.5768b_1 = 3.0289$$

The resulting value of b_1, -0.005% nitrogen per unit increase in the temperature coefficient, is negligible.

Replacing the temperature coefficients for the first period by those for the second gave

$$\begin{aligned} 196.8993b_0 - \ 5.5323b_2 &= -13.3427 \\ -5.5323b_0 + 37.0529b_2 &= \ \ 3.4191 \end{aligned}$$

resulting in $b_2 = +0.082 \pm 0.038$, the estimated standard error of b_2, s_{b_2}, being calculated from the relation

$$s_{b_2} = \sqrt{\frac{s^2\Delta_{22}}{\Delta}}$$

where s^2 is the mean square residual and Δ_{22} is the minor obtained by eliminating the second row and column of the determinant Δ formed from the numerical coefficients on the left hand side of the preceding equations (10, sec. 122).

Similar computations employing the temperature coefficients for the third period, August 12–September 1, had as their outcome

$$\begin{aligned} 196.8993b_0 - \ 5.1445b_3 &= -13.3427 \\ -5.1445b_0 + 39.7915b_3 &= \ \ 2.7894 \end{aligned}$$

and $b_3 = +0.062 \pm 0.037\%$ nitrogen per unit increase in the temperature coefficient.

There was therefore some indication that above-average temperature coefficients in the last two periods were associated with above-average nitrogen content. Seasonal fluctuations in the temperature coefficients for these two periods proved, however, not to be statistically independent; consequently, a portion of the apparent correlation between nitrogen content and the temperature coefficient for the second period is really due to the association of both with the temperature coefficient for the third period, and *vice versa*. When the sum of the temperature coefficients for the second and third periods was employed as a single independent variable, the resulting normal equations were

$$\begin{aligned} 196.8993b_0 - \ 10.6768b_{23} &= -13.3427 \\ -10.6768b_0 + 103.1914b_{23} &= \ \ 6.2085 \end{aligned}$$

and b_{23} assumed the more moderate value of $+0.053 \pm 0.022$. This is, however, still significantly greater than its standard error, and the degree of association with nitrogen content is measured by a partial correlation coefficient of $r = +0.33$, slightly in excess of the 5% point, 0.28. The value of b_0, the partial regression coefficient of nitrogen content on May and June rainfall after allowing for the temperature effect, is $-0.065 \pm 0.016\%$ nitrogen per additional inch of rain. The seasonal standard deviation of rainfall is approximately 1.4 times that of the sum of the two temperature coefficients, whereas the partial regression coefficient of nitrogen content on the combined temperature coefficients (b_{23}) is only about 0.8 of b_0, the partial regression coefficient on May and June rainfall. The temperature effects revealed by this analysis were thus a less potent source of variation in nitrogen content than were the fluctuations in rainfall.

In order to obtain a valid estimate of the relation for the two individual periods, the partial regression of nitrogen content on May and June rainfall and on the temperature coefficients for the second and third periods had to be determined simultaneously. The normal equations now became

$$\begin{aligned} 196.8993b_0 - 5.5323b'_2 - 5.1445b'_3 &= -13.3427 \\ -5.5323b_0 + 37.0529b'_2 + 13.1735b'_3 &= 3.4191 \\ -5.1445b_0 + 13.1735b'_2 + 39.7915b'_3 &= 2.7894 \end{aligned}$$

giving $b'_2 = +0.069 \pm 0.040$ and $b'_3 = 0.039 \pm 0.039$. Both coefficients are now less than twice their respective standard errors, indicating that the changes in nitrogen content associated with the temperature coefficient for a single period were not sufficiently pronounced to ensure their differentiation from the residual variation. The difference between b'_2 and b'_3 is also insignificant in comparison with its standard error, and cannot be regarded as plausibly suggesting a greater effect of temperature fluctuations in the second period.

Relation between Vegetative Growth, Yield and Nitrogen Content

In addition to the observations on yield and nitrogen content of grain already published (3, Table I) measurements of the average height of the plants were made at intervals throughout each growing season at each station. In so far as the final height attained provides an index of vegetative growth therefore, it was possible to investigate the relation between growth, yield and nitrogen content.

TABLE II

FINAL HEIGHT ATTAINED BY CROP (INCHES)

Station	Year	Height	Station	Year	Height
Lacombe, Alberta	1915	54	Indian Head, Saskatchewan	1928	49
	17	52		29	33
	21	46		31	26
	22	34		32	38
	25	43			
	28	55	Scott, Saskatchewan	1915	46
	30	38		17	26
	31	48		18	17
	32	54		21	34
				23	45
Lethbridge, Alberta	1915	48		24	20
	16	41		25	35
	17	33		26	28
	21	27		29	31
	22	36		30	34
	25	33		31	33
	26	36		32	36
	27	20			
	28	44	Rosthern, Saskatchewan	1915	39
	29	24		21	33
	30	32		22	48
	31	24		24	20
	32	33		25	41
				26	30
Indian Head, Saskatchewan	1915	48		27	48
	18	34		28	48
	24	38		29	27
	25	43		30	34
	26	44		32	32

The height attained by the various crops is shown in Table II. Seasonal variations gave rise to a standard deviation of 8.3 in., or 22.5% of the general mean, 36.9 in., and were therefore relatively less pronounced than the seasonal differences in yield and nitrogen content of grain, 41.8 and 29.6% of the mean respectively (3). The seasonal covariance of height and yield was computed to be 250387.6, and the sum of the squared deviations of the two quantities to be 3391.60 and 33,440,027, resulting in a coefficient of correlation of +0.74 (1% point = 0.36).

Previous calculations (3) had yielded a coefficient of correlation between nitrogen content and yield of $r = -0.40$. It was now found however that there was also an association between height and nitrogen content, giving a coefficient of $r = -0.50$; and when the coefficient of partial correlation between nitrogen content and yield after eliminating variations in both associated with height was determined, this was reduced to the negligible value of $r = -0.07$.

By the analysis described in the preceding paragraph, the seasonal variance of nitrogen content and yield was divided into two portions, of which one was associated with variations in height (*i.e.*, vegetative development). The other must be attributable to environmental factors not reflected in height or operative after elongation has ceased. This cessation occurs, under western Canadian conditions, about one week after flowering and from three to five weeks, depending on the season, before maturity. As the previously observed negative correlation between nitrogen content and yield arose from variations in these quantities associated with height differences, it would seem that any reductions in yield, due to restriction of the later stages of translocation, which occurred did not result in a significant modification of the nitrogen content of the grain.

General Conclusions

The results of this investigation as a whole are consistent with the supposition, inferred from chemical evidence in the introductory section of the present paper and stated explicitly by Russell and Bishop in connection with their studies on barley (7), that the nitrogen content of the grain is largely determined by conditions prevailing prior to the onset of translocation. This would certainly seem to be true of rainfall effects, and presumably of soil effects also.

On the other hand the views of McGinnis and Taylor with respect to the role of respiration (6) are also circumstantially supported, since the exponentially weighted temperature coefficients showed a significant correlation with nitrogen content whereas the linear temperature averages did not; and there remains the possibility that had more definite information respecting the temperature quotient of respiration been available, a more pronounced effect of temperature might have been demonstrated.

The theory that seasonal variations in moisture supply during the later weeks of development and ripening of the kernel are of prime importance in determining the composition of the grain is not, however, upheld by the present findings.

Acknowledgments

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References

1. BLACKMAN, V. H. Agricultural meteorology in its plant physiological relationships. Papers and Discussions of the Conference of Empire Meteorologists, 1929 (Agricultural Section) : 21-33. 1929.
2. BRENCHLEY, Winifred E. and HALL, A. D. The development of the grain of wheat. J. Agr. Sci. 3 : 195-217. 1909.
3. HOPKINS, J. W. Influence of weather conditions on the nitrogen content of wheat. Can. J. Research, 12 : 228-237. 1935.
4. LUNDEGÅRDH, H. Environment and plant development. Edward Arnold and Co., London. 1931.
5. MCCALLA, A. G. and NEWTON, R. Effect of frost on wheat at progressive stages of maturity. II. Composition and chemical properties of grain and flour. Can. J. Research, C, 13 : 1-31. 1935.
6. MCGINNIS, F. W. and TAYLOR, G. S. The effect of respiration upon the protein percentage of wheat, oats and barley. J. Agr. Research, 24 : 1041-1048. 1923.
7. RUSSELL, E. J. and BISHOP, L. R. Investigations on barley. J. Inst. Brew. 39 : 287-421. 1933.
8. THATCHER, R. W. The progressive development of the wheat kernel. J. Am. Soc. Agron. 5 : 203-213. 1913.
9. THATCHER, R. W. The progressive development of the wheat kernel. II. J. Am. Soc. Agron. 7 : 273-283. 1915.
10. WHITTAKER, E. T. and ROBINSON, G. The calculus of observations. (Second edition). Blackie and Son Ltd., London. 1929.
11. WOODMAN, H. E. and ENGLEDOW, F. L. A chemical study of the composition of the wheat grain. J. Agr. Sci. 14 : 563-586. 1924.

A STUDY OF MOISTURE CHANGES IN STANDING GRAIN[1]

By R. K. Larmour[2], W. F. Geddes[3], J. G. Malloch[4] and A. G. McCalla[5]

Abstract

A study of the moisture changes in standing grain during and after the ripening period was conducted at Winnipeg, Saskatoon and Edmonton in 1932 and 1933 with a view to obtaining information on the problem of combine harvesting.

Grain was found to be fit for binding four to seventeen days earlier than for straight combining.

There was no evidence that fully ripened grain at moisture contents of 11–13% can absorb sufficient moisture at night, owing to the higher relative humidity, to exceed 14·4% and become tough.

The rate of moisture loss in wet mature grain is much greater than the moisture loss, through the same range, in immature grain.

It is well known that wheat and other cereal grains lose moisture quite rapidly during maturation, but there is little definite information regarding the rate of loss under the climatic conditions encountered in Western Canada. Wheat that is ready for the binder usually contains from 20 to 35% moisture. In straight combining it is necessary to postpone harvesting until the moisture content has dropped to about 14% and the time necessary to bring this about is of considerable interest in relation to the choice of a method of harvesting.

Furthermore, in straight combining, cognizance must be taken of the possibility that during the night, when the relative humidity becomes high, the ripe dry grain may absorb enough moisture to make it tough in the morning, with the consequence that if operations are started too early in the morning or continued too late at night, the grain may carry an undesirable percentage of moisture. Numerous laboratory experiments have shown that the cereal grains are hygroscopic, and several studies have been conducted to determine the moisture content which will be attained when they are kept in atmospheres of different relative humidity. For example, Coleman and Fellows (1) found that at relative humidities of 15%, 45%, 75%, 90% and 100% the corresponding moistures of hard red spring wheat were 7·3%, 11·2%, 17·3%, 24·6% and 33·4% respectively. These are the percentages finally attained by the wheat, but it must be exposed six to eight days before these values are reached. For immature grain of high moisture content, the vapor pressure of the grain would exceed the partial pressure of water vapor in the air, even at the higher relative humidities during the night, and hence the grain would continue drying. However, as it matures it ultimately attains moisture contents at which its vapor pressure becomes lower than the

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partial pressure of water vapor in the air at the lower temperatures of the night. At this point it might be expected to lose moisture during the day and regain some of it at night. With grain bordering on "tough" this might become an important factor in straight combining. With these considerations in mind, an investigation was undertaken to determine the course of moisture variation in standing grain during its maturation period and also to ascertain the changes that might be expected to occur in fully ripened grain as a result of fluctuations in the relative humidity during 24-hr. periods. At Winnipeg, standing plots of Reward wheat and O.A.C. 21 barley were used. At Saskatoon and Edmonton, plots of Marquis wheat were sampled.

From approximately ten days after flowering, the plots were sampled at 2 p.m. daily until the grain reached a moisture content of about 45%. From that stage until the grain was dead ripe, sampling was done at 2-hr. intervals from 8 a.m. to 8 p.m. inclusive in 1932, and from 6 a.m. to 10 p.m. inclusive in 1933. During the 1932 experiments, heads were taken at random over the whole plot, transferred to air-tight containers, threshed either by hand or in a small head-thresher, and tested for moisture immediately on returning to the laboratory. In 1933 a modification of the method of sampling was used. The plots were divided into sections, which were numbered and randomized; all the heads in a given section were taken and duplicate samples were collected at each sampling period. Until the moisture reached 15%, the determinations were made in two stages. A large sample of 30 to 40 gm. was given a first drying by heating in an air oven at 98° C. for 5 hr. Moisture loss on this was determined, the grain was then ground and the residual moisture determined on a 2 gm. sample in the usual way.

Records of temperature and relative humidity were made either at each reading or by means of a recording instrument. Average wind velocity, hours of sunshine and rainfall were obtained from the meteorological records (a Class I station is located at each point). At Winnipeg a record was kept of the daily evaporation.

The complete data are too bulky for inclusion in this paper, therefore only the summary of the moisture results, together with graphs showing moisture, temperature, humidity, sunshine, rainfall and wind velocity are presented.

As this work comprises three separate and distinct experiments, each carried on under different climatic conditions in two successive seasons, they will be discussed separately.

Rate of Drying of Barley at Winnipeg, 1932

Sampling of the barley plot at Winnipeg began on July 30, 1932, the moisture content of the grain at that time being 60·3%. One sample per day was taken until Aug. 5, by which time the moisture had fallen to 48·2% and thereafter sampling was carried on at 2-hr. intervals from 8 a.m. to 8 p.m. daily until Aug. 15, when the moisture had fallen to below 13%. The data are given in Table I and shown graphically in Fig. 1. The meteorological data for this period are given in Table XIII. This period at Winnipeg was charac-

terized by gradually increasing temperature during the day, long duration of bright sunshine, moderate wind velocities and little rain; almost ideal conditions for studying rate of desiccation of maturing grain in normal hot dry weather.

TABLE I

MOISTURE CONTENT OF STANDING BARLEY AT 2-HR. INTERVALS FROM 8:00 A.M. TO 8:00 P.M. DURING RIPENING PERIOD AT WINNIPEG, 1932

Date	Moisture content at							Daily mean, %
	8 a.m. %	10 a.m. %	12 a.m. %	2 p.m. %	4 p.m. %	6 p.m. %	8 p.m. %	
Aug. 6	48.7	48.0	48.9	48.3	46.5	43.9	46.4	47.2
7	46.3	45.5	46.0	45.0	45.8	45.8	44.6	45.6
8	45.4	43.7	43.9	43.6	43.7	43.1	43.4	43.8
9	42.5	41.8	41.5	40.5	39.2	40.6	40.8	41.0
10	37.7	38.4	41.0	38.8	34.9	34.8	37.4	37.6
11	36.4	36.3	34.8	34.2	30.6	32.8	31.9	33.9
12	34.0	31.0	29.7	28.0	29.0	31.3	25.2	29.7
13	28.0	28.2	25.9	25.8	25.2	26.7	25.8	26.5
14	22.1	22.9	21.6	20.7	20.6	21.0	17.9	21.0
15	16.0	13.3	13.8	11.1	11.6	12.1	14.4	13.2
16	15.9	14.9	15.0	14.3	13.4	12.0	13.0	

	10 p.m.	12 p.m.	2 a.m.	4 a.m.	6 a.m.
Aug. 15 and Aug. 16	14.5	16.5	16.7	16.2	16.2

It will be noted in Fig. I that the moisture content fell rather slowly from about 48% on August 6 to 36% at 8 a.m. August 11, and thereafter more rapidly until at midday August 15 it had decreased to 14.3%. This was obviously the earliest date at which combining might be started if straight grade grain were desired. This grain, however, was judged fit for cutting with the binder on August 11. At that time the moisture was between 31 and 34%. It would have been necessary, therefore, to wait four days after binding started to commence combining, even with the ideal weather conditions that prevailed during this period.

There seems to have been no pronounced rise in moisture content during the night until the grain decreased to about 12% moisture. The rise indicated on the morning of August 13 was probably due to sampling error, because the second and third samples for that day rose successively, although the temperature had risen as usual quite sharply. To get more accurate information concerning the change in moisture content of the grain during the night, the barley plot was sampled at 2-hr. intervals from 8 a.m. August 15 to 8 p.m August 16. From a moisture content of 16% at 8 a.m. the grain dried to 11.1% at 2 p.m. and then increased to 14.4% at 8 p.m. the same evening. The maximum moisture, 16.7%, was recorded at 2 a.m. the following morning. This fell to 15.9% at 8 a.m., an increase of 1.5% over the value obtained at 8 p.m. the previous evening. The increase is not great, but it is of significance in relation to the time at which combines may resume work.

Rate of Drying of Reward Wheat at Winnipeg, 1932

The data on moisture in the wheat samples are given in Table II and shown graphically in Fig. 1.

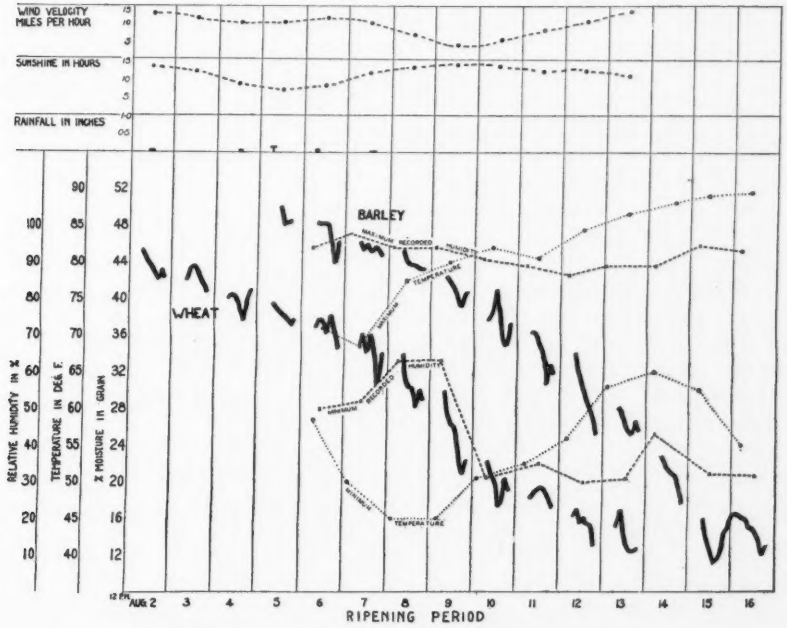

FIG. 1. *Changes in moisture content of Reward wheat and O.A.C. 21 barley, and weather conditions at Winnipeg, 1932.*

TABLE II

MOISTURE CONTENT OF STANDING WHEAT AT 2-HR. INTERVALS FROM 8:00 A.M. TO 8:00 P.M. DURING RIPENING PERIOD AT WINNIPEG, 1932

Date	Moisture content at							Daily mean, %
	8 a.m. %	10 a.m. %	12 a.m. %	2 p.m. %	4 p.m. %	6 p.m. %	8 p.m. %	
Aug. 2	45.4	43.5	44.6	42.9	42.0	43.2	42.3	43.4
3	42.0	43.3	43.5	—	—	—	40.7	42.4
4	40.0	40.5	40.1	39.0	37.6	40.5	40.9	39.8
5	39.5	38.4	39.2	37.0	38.2	36.8	37.5	38.1
6	36.8	37.8	37.5	35.9	38.2	36.4	34.3	36.7
7	34.9	36.1	33.9	36.0	34.9	30.6	33.9	34.3
8	33.8	30.9	30.2	30.2	28.0	30.0	29.0	30.3
9	29.9	25.9	26.7	26.0	22.0	20.8	22.3	24.8
10	22.2	20.8	20.2	17.3	17.7	20.3	19.0	19.6
11	18.2	18.8	19.2	19.3	19.0	—	17.2	18.6
12	16.3	17.0	15.5	16.1	15.4	15.1	13.0	15.5
13	15.1	16.9	14.6	12.9	12.4	12.5	12.8	13.9

Sampling of wheat at 2-hr. intervals was commenced at 8 a.m. August 2 and continued until 8 p.m. August 13. The grain was judged fit for cutting with the binder on August 6. At this date the moisture content was about 36%. It was not under 14.4% until 2 p.m. August 13. This means that combine harvesting could not have been started until seven days after binder cutting.

In this series there is no pronounced evidence of increase in moisture content during the night. At 8 p.m. August 12 the moisture was 13.0%, having dropped from 15.1% at 6 p.m. that day; the following morning at 8 a.m. it was 15.1% which looks like an increase due to higher humidity during the night. It appears probable, however, that the value 13% ought to be considered an error due to sampling.

It is interesting to note that the standing barley took eight days to dry from 45% to 12% moisture, while the Reward wheat required 12 days for the same change. This is accounted for by the fact that light showers occurred on all but one day during the period August 2–7 inclusive. Even though the showers were slight and generally of short duration, as can be seen from the hours of bright sunshine, and there were moderate winds, these rains effectively retarded drying to the extent that during these six days the wheat changed only from 45.4 to 33.8% moisture, whereas during the next six days it changed from 33.8 to 12.8%.

Rate of Drying of Barley at Winnipeg, 1933

In 1933 barley only was used at Winnipeg. Sampling at 2-hr. intervals commenced on August 9 and continued until August 27. The average

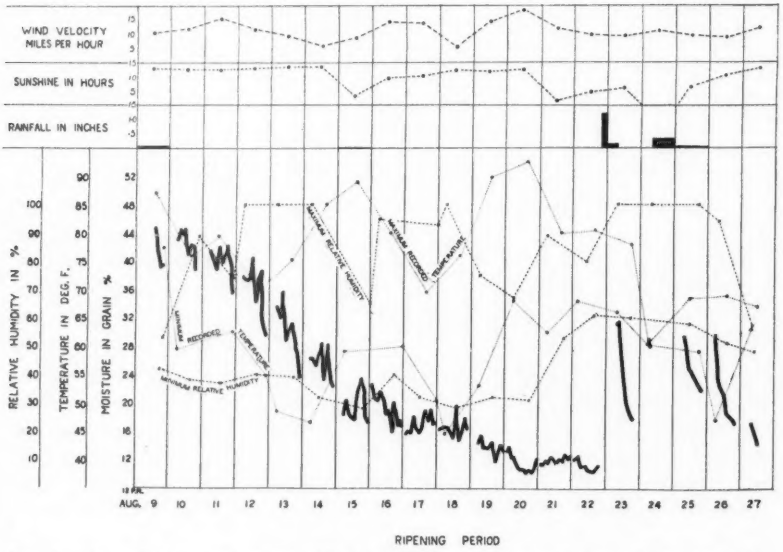

FIG. 2. *Changes in moisture content of O.A.C. barley, and weather conditions at Winnipeg, 1933.*

moisture for each sampling is given in Table III and shown graphically in Fig. 2. The meteorological data are given in Table XIV.

TABLE III

MOISTURE CONTENT OF BARLEY IN STANDING GRAIN AT 2-HR. INTERVALS FROM 2:00 A.M. TO 12:00 P.M. DURING RIPENING PERIOD AT WINNIPEG

Date	Moisture content at												Daily mean, %
	2 a.m. %	4 a.m. %	6 a.m. %	8 a.m. %	10a.m. %	12 noon %	2 p.m. %	4 p.m. %	6 p.m. %	8 p.m. %	10p.m. %	12p.m. %	
Aug. 9	—	—	—	—	—	—	44.9	42.0	39.2	39.3	—	—	41.4
10	—	—	43.0	44.6	43.8	44.7	40.9	42.4	42.2	38.8	—	—	42.6
11	—	—	41.6	40.2	38.6	42.1	39.8	40.8	42.3	39.6	35.4		40.0
12	—	—	37.9	37.4	37.4	40.6	34.0	37.6	38.8	31.0	29.3	—	36.0
13	—	—	33.7	31.8	35.8	28.6	30.2	31.2	28.0	27.3	23.4	—	30.0
14	—	—	26.3	26.3	25.2	26.9	28.4	23.1	28.3	23.2	22.2	—	25.5
15	—	—	18.2	20.3	18.4	17.8	17.5	21.9	23.4	21.9	18.0	16.8	19.4
16	22.6	20.7	20.2	21.7	21.2	18.2	19.1	15.8	20.0	16.6	17.6	16.6	19.2
17	15.5	16.1	15.7	18.1	16.4	15.5	16.4	18.9	17.3	19.0	16.9	17.0	16.9
18	16.2	16.4	16.6	16.6	16.1	14.8	19.7	14.6	15.5	17.8	16.2	—	16.5
19	—	—	14.2	15.4	13.6	13.6	13.6	14.4	11.5	12.8	14.1	12.8	13.6
20	13.1	13.8	12.2	12.3	11.0	10.6	10.6	10.0	10.6	10.0	10.6	12.2	11.4
21	11.3	11.3	11.8	11.4	12.4	11.6	11.5	12.1	11.6	12.7	12.0	12.6	11.9
22	12.0	12.2	12.5	10.8	11.0	10.4	10.2	10.2	10.6	11.1	Rain		11.1
23	Rain			31.2	31.5	25.8	21.4	—	18.2	17.5	—	—	24.3
24	Rain		29.0	28.0	Rain								28.5
25	—	—	—	29.4	27.3	24.6	24.1	23.1	22.4	21.6	—	—	24.6
26	—	—	29.6	24.2	22.0	21.2	18.6	18.4	17.6	17.0	—	—	21.1
27	—	—	—	17.0	15.6	14.0	—	—	—	—	—	—	15.5

Beginning on August 9 with a moisture content of 44.9%, the grain dried rapidly until August 13, when it reached an average daily moisture content of 30% and was fit for binder cutting. It required six days longer, or until August 19, before it would have been harvested safely by straight combining. Between 8 p.m. August 22 and 6 a.m. August 23, precipitation to the amount of 1.22 in. occurred. This caused an abrupt rise in moisture content to 31%. Showers during the next three days prevented rapid drying and it was not until noon, August 27, that the grain on this plot contained less than 14.4% moisture and could be considered fit for straight combining.

Rate of Drying of Marquis Wheat at Saskatoon

In 1932, sampling of the wheat plot at Saskatoon began on August 4 when the moisture content of the grain was 40%. The grain was judged fit for binding on the afternoon of August 5, at which time the moisture content was 33–34%. By the afternoon of August 9 this had decreased to less than 14.4% and the grain was fit for straight combining. The rate of drying was rapid, owing to hot dry days with moderate winds and long hours of bright sunshine. Sampling was continued until August 27 in order to observe the effect of rains. The data are given in Table IV and shown graphically in Fig. 3.

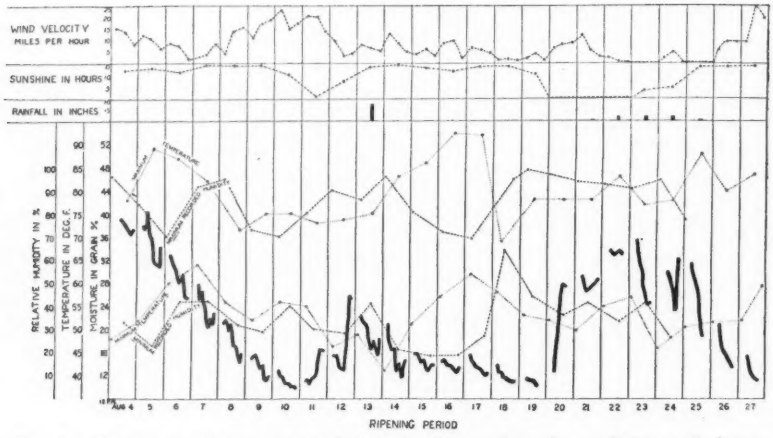

FIG. 3. *Changes in moisture content of Marquis wheat, and weather conditions at Saskatoon, 1932.*

TABLE IV

MOISTURE CONTENT OF STANDING MARQUIS WHEAT AT 2-HR. INTERVALS FROM 5:00 A.M. TO 9:00 P.M. DURING RIPENING PERIOD AT SASKATOON, 1932

Date	Moisture content at									Daily mean, %
	6 a.m. %	8 a.m. %	10 a.m. %	12 noon %	2 p.m. %	4 p.m. %	6 p.m. %	8 p.m. %	10 p.m. %	
Aug. 4	—	—	39.3	—	—	37.7	37.3	36.3	37.2	37.6
5	37.8	37.3	40.5	36.7	36.3	31.6	31.2	30.8	34.3	35.2
6	32.9	31.9	31.4	30.4	27.9	29.8	28.3	25.7	25.4	29.3
7	27.9	25.0	26.8	25.4	22.2	20.1	22.0	20.7	22.8	23.6
8	21.1	21.8	19.5	20.9	17.2	17.3	15.3	14.1	15.8	18.1
9	15.0	15.5	15.7	15.3	13.1	13.4	11.4	11.0	11.9	13.6
10	12.8	11.8	11.9	11.1	10.6	10.8	10.0	10.1	9.9	11.0
11	11.2	11.3	10.4	11.7	11.8	12.3	16.4	16.5	16.1	13.1
12	15.5	15.3	15.7	13.5	13.3	12.7	—	25.9	25.3	17.1
13	22.4	21.4	21.2	20.5	17.6	16.3	18.0	15.2	18.2	19.0
14	20.9	17.4	16.2	16.7	12.7	14.0	11.2	13.8	14.6	15.3
15	15.9	15.8	15.0	14.3	14.6	13.4	12.8	13.8	13.8	14.4
16	14.4	14.7	13.9	13.7	13.7	13.2	12.7	12.6	13.4	13.6
17	15.6	14.3	14.2	13.3	13.3	12.8	12.1	11.9	12.3	13.3
18	13.7	12.5	12.5	11.7	11.7	11.1	11.1	11.0	11.1	11.8
19	—	11.6	—	—	11.0	—	10.1	—	—	10.9
20	—	12.5	—	—	27.8	—	27.5	—	—	22.9
21	—	29.2	—	26.6	—	27.3	—	—	28.8	28.0
22	—	33.7	—	32.8	—	33.7	—	33.0	—	33.3
23	—	35.5	—	30.5	27.5	—	24.1	24.4	—	28.4
24	—	—	29.9	—	28.2	26.5	23.2	32.2	—	28.0
25	—	31.4	29.2	27.5	23.7	21.7	18.6	—	—	25.4
26	—	20.9	18.0	16.5	16.1	15.4	14.0	13.3	—	16.3
27	—	15.3	14.2	12.9	12.1	11.4	11.2	—	—	12.9

In 1933 sampling of a Marquis wheat plot was commenced on August 1, when the moisture content of the wheat was 40%. The grain was judged fit for binding on August 4, when the moisture had fallen to about 32–33%.

Six days later, August 10, the moisture content was less than 14.4% and the wheat was fit for straight combining. Then followed a period of eleven days, August 10–20 inclusive, of ideal harvest weather, during which there were uniformly long "hours of bright sunlight", light winds, high daily temperatures, a very uniform range of relative humidity, and only one slight shower of rain. Thereafter the weather became somewhat unsettled with cloudy days and occasional rains. The sampling was continued until September 25, in order to observe the rate of drying in the latter part of the harvest season. The moisture data are given in Table V and in Fig. 4. The meteorological data are given in Table XVI.

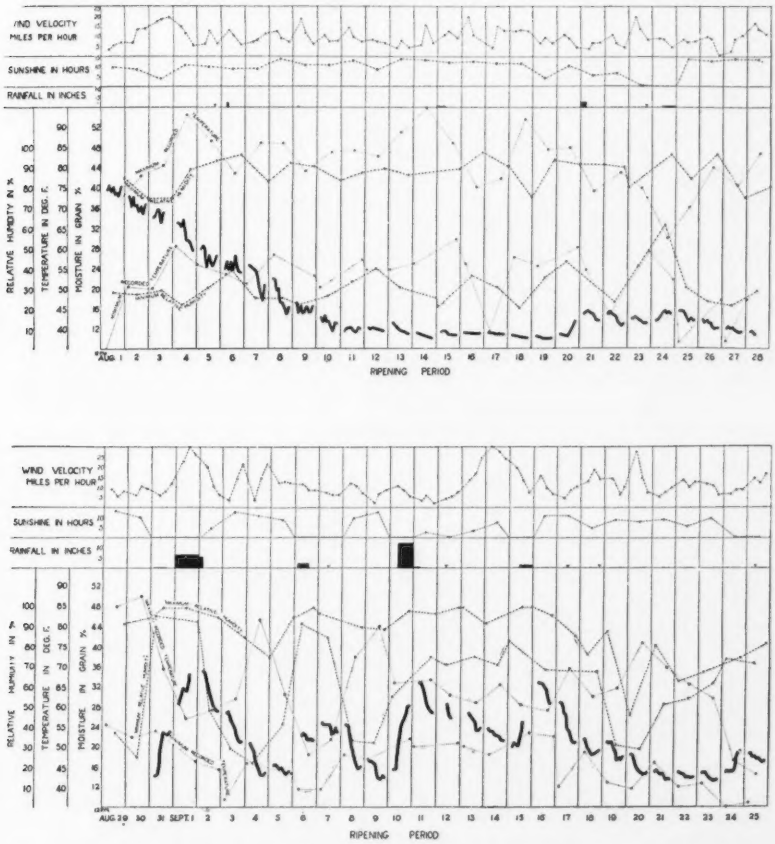

FIG. 4. *Changes in moisture content of Marquis wheat, and weather conditions at Saskatoon, 1933.*

TABLE V

MOISTURE CONTENT OF STANDING MARQUIS WHEAT AT 2-HR. INTERVALS FROM 5:00 A.M. TO 9:00 P.M. DURING RIPENING PERIOD AT SASKATOON, 1933

Date	Moisture content at									Daily mean, %
	6 a.m. %	8 a.m. %	10 a.m. %	12 noon %	2 p.m. %	4 p.m. %	6 p.m. %	8 p.m. %	10 p.m. %	
Aug. 1	—	39.6	40.6	39.0	40.1	38.6	39.0	38.3	40.2	39.4
2	38.2	36.2	38.0	36.4	36.5	35.2	36.2	34.8	36.5	36.4
3	34.1	34.3	35.8	35.7	33.1	35.0	—	—	—	34.7
4	33.1	33.0	32.3	33.7	31.9	29.8	29.4	28.2	27.3	31.0
5	27.9	28.5	27.5	24.2	26.7	25.3	24.3	—	26.3	26.3
6	23.9	25.5	23.8	25.4	23.7	26.4	24.6	23.2	22.8	24.4
7	24.6	24.2	23.8	23.5	23.3	20.7	18.9	17.5	20.5	21.9
8	21.9	21.7	19.6	19.9	17.2	17.1	15.8	14.8	16.0	18.2
9	17.2	14.9	16.4	14.9	15.2	16.4	15.1	15.4	16.4	15.8
10	14.1	13.1	14.6	13.2	13.2	12.6	11.5	13.0	13.0	13.1
11	11.6	12.0	12.2	12.3	12.1	11.4	11.3	12.2	11.8	11.9
12	12.0	11.8	12.1	12.0	—	—	—	—	11.6	11.9
13	13.1	—	—	—	11.5	—	—	—	10.8	11.8
14	11.1	—	—	—	10.5	—	—	—	9.9	10.5
15	11.3	11.5	11.5	11.3	10.9	—	—	—	10.6	11.2
16	1 2	—	—	—	11.0	—	—	—	11.1	11.1
17	11.2	—	—	—	10.8	—	—	—	10.8	10.9
18	10.6	—	—	—	10.3	—	—	—	10.1	10.3
19	10.3	—	—	—	9.9	—	—	—	10.0	10.1
20	10.8	—	—	—	10.4	—	—	—	13.4	11.5
21	14.8	15.4	15.6	15.3	15.2	14.7	13.9	13.6	13.5	14.7
22	14.8	15.3	14.9	14.6	14.3	13.3	13.0	12.5	12.8	13.9
23	13.9	13.9	14.2	14.0	13.6	13.5	13.0	13.0	13.0	13.6
24	13.3	13.5	13.9	14.7	15.2	15.4	14.9	15.1	14.7	14.5
25	15.3	15.3	15.3	14.8	14.2	13.2	13.9	13.5	13.5	14.3
26	13.6	13.0	13.4	12.9	12.9	12.2	11.7	11.9	11.9	12.6
27	11.9	12.3	11.9	11.9	11.7	11.3	11.1	11.0	11.1	11.6
28	11.2	11.4	10.9	10.6	—	—	—	—	—	11.0
29	—	—	—	—	10.9	—	—	—	—	10.9
30	—	—	—	—	11.1	—	—	—	—	11.1
31	14.4	14.4	15.2	—	23.0	22.7	22.4	22.5	23.1	19.7
Sept. 1	28.5	30.6	31.8	—	31.2	34.5	—	—	—	31.3
2	35.2	34.8	33.8	31.9	30.9	29.0	27.9	27.2	27.1	31.0
3	26.8	27.1	26.1	25.2	24.1	22.6	21.6	20.9	20.9	23.9
4	20.7	19.9	19.4	17.4	16.4	14.8	14.3	14.2	14.9	16.9
5	16.3	16.5	16.2	15.7	15.8	15.0	14.8	14.6	15.2	15.6
6	—	—	22.2	22.8	22.2	21.4	21.6	21.5	21.2	21.8
7	24.7	24.4	24.4	24.4	24.3	22.4	22.5	23.8	22.7	23.7
8	24.5	24.3	23.9	20.4	19.4	17.9	16.1	15.7	16.1	19.8
9	17.2	17.2	16.8	16.8	15.2	13.8	13.5	14.4	13.9	15.4
10	15.5	15.5	19.1	22.5	24.9	25.9	27.0	28.1	28.2	23.1
11	—	32.7	32.9	31.9	30.3	28.4	27.8	27.1	26.7	28.4
12	—	—	—	28.5	26.4	25.6	—	—	—	26.8
13	—	—	26.7	26.3	25.5	25.1	23.3	23.2	23.7	24.8
14	23.6	23.2	23.1	22.4	22.2	22.0	21.3	21.3	21.2	22.3
15	19.9	20.8	20.3	20.1	22.8	24.9	—	—	—	21.5
16	—	32.7	—	32.6	—	31.5	—	28.4	—	31.3
17	28.8	28.6	26.8	26.5	23.4	22.6	21.0	20.7	20.8	24.4
18	21.4	21.5	19.8	19.2	18.3	18.2	18.3	18.7	19.0	19.4

The Rate of Drying of Marquis Wheat at Edmonton

Sampling of the Marquis wheat plot at Edmonton in 1932 was commenced on August 23, when the moisture content of the wheat was 48%. On August 29 the daily average moisture content had fallen to 34% and the grain was

ready for binding. After that, the rate of drying was slow, owing to frequent light showers, and it was not until September 11, 13 days later, that the moisture content was less than 14.4% so that the grain could be considered fit for straight combining. Sampling was continued until September 14. The moisture data are given in Table VI and in Fig. 5; the meteorological data are to be found in Table XVII.

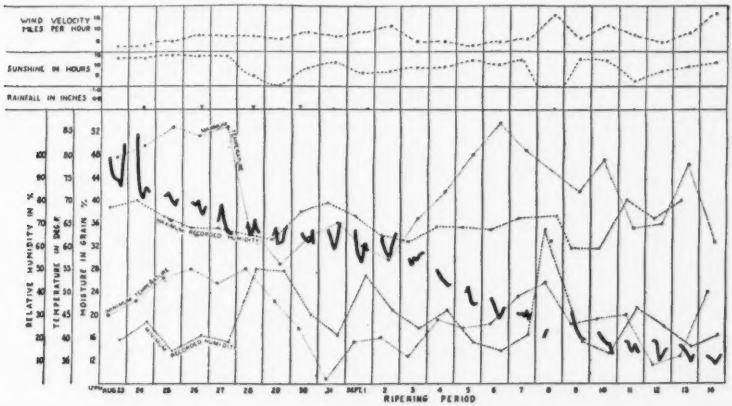

FIG. 5. *Changes in moisture content of Marquis wheat, and weather conditions at Edmonton, 1932.*

TABLE VI

MOISTURE CONTENT OF STANDING MARQUIS WHEAT AT 2-HR. INTERVALS FROM 8:00 A.M. TO 8:00 P.M. DURING RIPENING PERIOD AT EDMONTON, 1932

Date	Moisture content at							Daily mean, %
	8 a.m. %	10 a.m. %	12 a.m. %	2 p.m. %	4 p.m. %	6 p.m. %	8 p.m. %	
Aug. 23	47.5	44.4	43.8	43.6	43.7	42.5	49.9	45.0
24	51.6	42.8	40.3	40.4	42.4	41.4	42.1	43.0
25	40.8	40.8	41.4	40.0	40.7	39.0	40.2	40.4
26	39.7	39.5	39.0	39.9	37.9	37.5	38.9	38.9
27	36.2	39.3	37.4	34.9	34.9	34.5	34.1	35.9
28	35.1	35.9	33.7	34.9	36.6	34.9	34.4	35.1
29	33.8	35.3	32.2	33.0	32.6	34.9	35.4	33.9
30	33.8	34.3	33.0	33.5	32.6	34.7	32.4	33.5
31	34.8	33.4	33.4	31.4	32.0	36.0	—	33.5
Sept. 1	34.7	31.0	31.0	29.0	32.7	31.1	31.6	31.6
2	33.5	29.5	31.9	30.0	30.7	33.2	34.2	31.8
3	29.8	28.4	30.1	29.4	29.9	30.6	30.7	29.8
4	27.8	26.7	25.9	25.9	26.2	24.9	25.2	26.1
5	31.8	23.9	24.9	22.0	22.4	21.6	22.0	24.1
6	22.9	22.0	21.2	19.9	19.3	20.3	21.2	21.0
7	20.2	19.9	20.3	19.4	20.7	19.0	20.0	19.6
8	15.9	17.1	Rain					
9	20.4	17.9	17.9	17.2	15.6	16.1	15.7	17.2
10	16.8	16.2	15.4	15.2	14.6	15.0	13.0	15.2
11	15.3	15.2	13.8	13.4	14.8	14.2	13.3	14.3
12	15.4	15.4	14.7	11.8	12.8	13.7	14.0	14.0
13	14.7	14.2	14.0	13.4	13.2	11.7	12.9	13.4
14	12.7	12.1	12.7	11.7	11.4	12.3	12.9	12.2

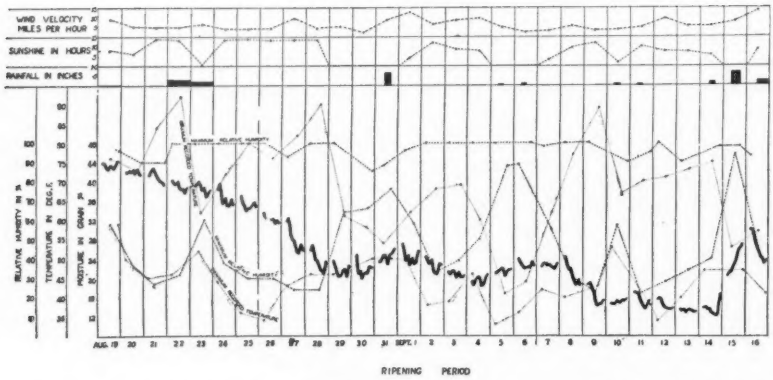

FIG. 6. *Changes in moisture content of Marquis wheat, and weather conditions at Edmonton, 1933.*

TABLE VII

MOISTURE CONTENT OF STANDING MARQUIS WHEAT AT 2-HR. INTERVALS FROM 6:00 A.M. TO 10:00 P.M. DURING RIPENING PERIOD AT EDMONTON, 1933

Date	Moisture content at									Daily average, %
	6 a.m. %	8 a.m. %	10 a.m. %	12 noon %	2 p.m. %	4 p.m. %	6 p.m. %	8 p.m. %	10 p.m. %	
Aug. 19	44	43.8	42.9	42.6	43.4	42.9	42.7	43.4	44.3	43.3
20	42	41.9	42.3	42	42.7	41.7	42.7	41.6	41.4	42.0
21	41.35	42.3	42.9	42	41.3	40.5	40	39.75	39.3	41.0
22	40.2	39.85	39.4	40.1	38.8	38.3	38.6	37.5	38.8	39.1
23	39.2	39.5	40.2	39.5	38.25	38.9	36.7	37.25	38.2	38.6
24	38.4	39.6	37.8	35.4	36.7	35	34.9	36.4	35.05	36.6
25	37.15	35.65	35.15	33.9	34.6	34.45	35.15	35.75	34.7	35.2
26	33.65	32.3	32.1	32.35	32.05	32.35	31.25	32.05	31.3	32.2
27	31.8	32.45	30.05	27.95	27.75	25.45	25	26.95	25.6	28.1
28	25.75	26.8	25.3	23.75	23.65	21.9	21.55	20.95	23.5	23.7
29	23.7	22.35	21.35	20.25	20.3	21.55	21.9	20.25	22.65	21.6
30	24.8	20.8	21.4	19.75	20.75	21.1	20.8	22.4	22.15	21.6
31	23.6	23.8	24.75	24.7	22.8	24.7	25.15	25.6	26.05	24.6
Sept. 1	27	25.5	23.35	24.7	22.55	24.15	22.7	23.2	25.65	24.3
2	24.45	23.65	22.8	23.8	21.45	20.7	20.65	22.95	22.7	22.6
3	21.3	20.65	21.55	21.25	20	21.25	20.15	20.1	20.55	20.8
4	19.35	18.45	19.55	20.3	19.8	18.25	18.55	20	20.75	19.4
5	20.95	21.2	21.5	22.0	21.9	20.25	21.6	21.85	21.85	21.5
6	23.95	23.15	22.4	21.9	21.95	22.35	22	23.4	22.55	22.6
7	22.55	23.05	23.05	22.7	22.7	22.55	22.15	21.95	23	22.6
8	24.3	23.05	21.7	21.95	20.25	19.25	18.4	19.6	18.35	20.8
9	18.85	19.05	17.45	17.1	15.25	14.25	14.7	14.65	15.35	16.3
10	14.75	14.6	14.5	15.3	14.85	14.7	15.45	15.2	15.65	15.0
11	17.15	16.8	16.5	15.4	14.75	14.2	13.55	14.3	15.55	15.4
12	15.65	15.9	15.55	14.15	13.8	13.7	13.55	13.55	13.7	14.4
13	13.6	13.3	13.6	12.8	13.6	13.55	13.25	13.1	13.15	13.3
14	14	14.05	13.65	13.75	13.05	12.5	12.35	12.35	16.8	13.6
15	20.4	21.25	21.35	21.9	23.2	24.7	25.9	26.4	27	23.6
16	30.5	29.8	28.75	26.7	25.6	24.35	24.15	22.95	23.75	25.3

The rate of drying at Edmonton in 1933 proved to be even slower than in 1932, owing to the occurrence of several fairly heavy rains. Sampling was begun on August 19, when the moisture content was 44%. By midday August 25, the moisture content had fallen to about 34% and the grain was fit for binding. By 4 p.m. September 11 the wheat was dry enough for straight combining. It required 17 days from the time when binder harvesting could have been started for the grain to reach the straight grade moisture level. Sampling was continued until September 16. The moisture data are given in Table VII and the meteorological data in Table XVIII. Both are shown graphically in Fig. 6.

Comparison of Rates of Drying

The foregoing brief discussion of the separate investigations of rates of drying of grain may be summarized for the purpose of comparison by tabulating, as in Table VIII, the times that elapsed between the dates on which the grain was ready for binder harvesting and those on which it had dried to below 14.4%, the upper limit for safe straight combining.

TABLE VIII

DATES ON WHICH BINDER HARVESTING AND STRAIGHT COMBINING HARVESTING COULD HAVE BEEN STARTED

Place and year	Grain	First date on which moisture content had fallen to below		Difference in days A to B
		A—35%	B—14.4%	
Winnipeg, 1932	Barley	Aug. 11	Aug. 15	4
Winnipeg, 1932	Reward wheat	Aug. 7	Aug. 12	5
Winnipeg, 1933	Barley	Aug. 12	Aug. 19	7
Saskatoon, 1932	Marquis wheat	Aug. 5	Aug. 9	4
Saskatoon, 1933	Marquis wheat	Aug. 3	Aug. 10	7
Edmonton, 1932	Marquis wheat	Aug. 28	Sept. 10	13
Edmonton, 1933	Marquis wheat	Aug. 25	Sept. 11	17

The course of the drying of standing grain at the three places is shown graphically in Fig. 7. The principal fact brought out by this presentation of the data is that in the two seasons under consideration the rate of drying of wheat from 35% to 14.4% moisture content was two to three times faster at Winnipeg and Saskatoon than at Edmonton. It should be noted that at Edmonton in each year binder harvesting was 22–23 days later than at Saskatoon, while straight-combine harvesting would have been 31–32 days later. The normal expectancy of favorable harvest weather at the three points is greater for August than for September and therefore the delay of about two weeks between binder harvesting and combine harvesting at Edmonton must be regarded as very hazardous.

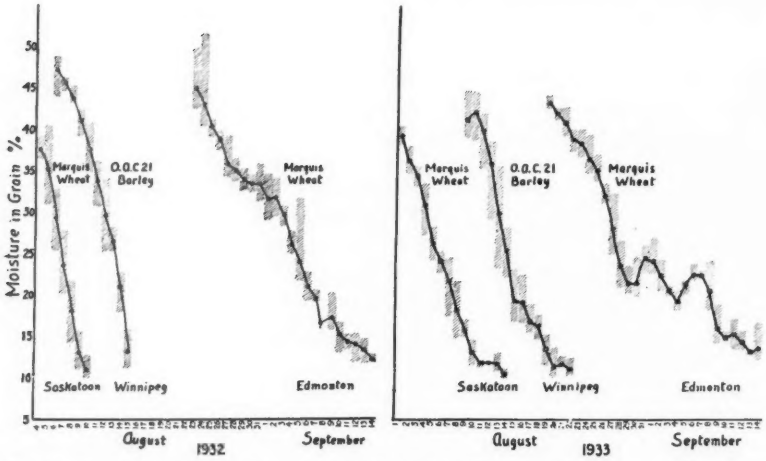

FIG. 7. *Comparison of rates of drying of standing grain at Winnipeg, Saskatoon and Edmonton.*

The Relation of Relative Humidity to Moisture of Standing Grain

It is commonly observed by combine operators that toward the end of the day and very early in the day, grain becomes too "tough" to handle properly. This is sometimes interpreted as meaning that the moisture content of the wheat increases to above 14.4%, the upper limit for straight grade wheat. It can be easily verified that the straw and more particularly the rachis frequently loses its brittleness late in the day, even during the most ideal harvesting weather. This is obviously due to the fall in temperature and the accompanying rise in relative humidity, which results in absorption of water vapor from the air by the straw. While no work has been reported on the relation of relative humidity to brittleness of straw, it seems reasonably certain from practical observation that the change takes place fairly rapidly.

The establishing of equilibrium between moisture content of grain and the humidity of the surrounding atmosphere is known to be a slow process, requiring from six to eight days when the air is circulated and from ten to twenty days in still air. Under the conditions of constantly changing relative humidity of a clear summer night, however, it is difficult to predict to what extent the moisture content of grain initially at 13–14% might increase. Laboratory experiments by one of the authors show that wheat at 11% moisture content, when exposed over water in a closed vessel, requires practically 12 hours to attain a moisture content of 14.4%. At lower relative humidities the rate of moisture increase is slower. From the practical point of view it is necessary to ascertain, if possible, whether or not wheat below 14.4% moisture may become tough over night, as a result of the increase in relative humidity. Part of the data obtained in this series of observations is suitable for study of this question.

In the Winnipeg 1933 data in Table III, there are 89 determinations of moisture of standing barley taken at consecutive 2-hr. intervals, covering the period 6 a.m. Aug. 15 to 10 p.m. Aug. 22, except for three samplings omitted at 12 p.m., 2 a.m. and 4 a.m. on the night of August 18. This period represented almost ideal harvesting weather, as can be seen from the meteorological data in Table XIV. The weather was mostly clear, with moderate winds, fairly high temperatures, long hours of sunshine and no rain except 0.02 in. on the first day, August 15. The moisture and relative humidity data for this

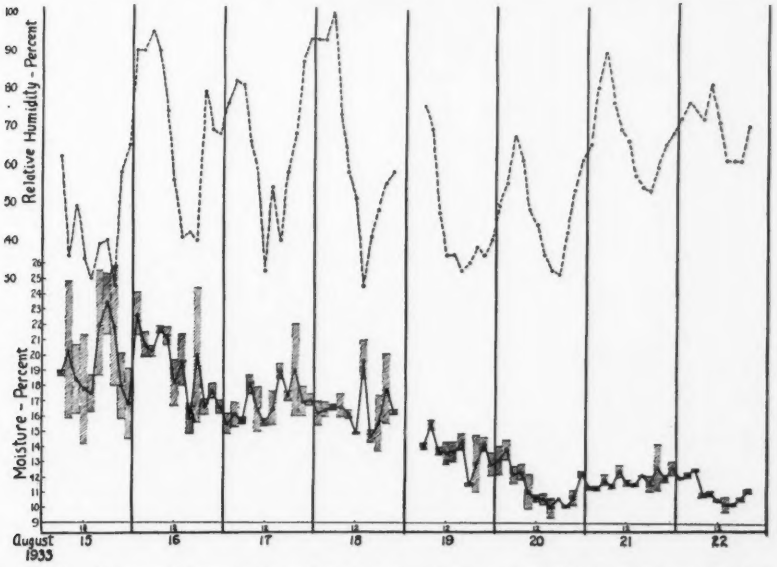

FIG. 8. *Upper and lower limits and average of moisture content of wheat samples collected at 2-hr. intervals for eight consecutive days at Winnipeg in 1933.*

period are shown in Fig. 8. The range of moisture represented by the duplicate samplings is shown by shaded columns and the averages by dots connected by the heavy line.

The relative humidity for the first six days approached an observed minimum of about 30% in the early afternoon and an observed maximum of 80–100% in the early morning at 4 a.m. or 6 a.m. The changes in relative humidity were rapid, both minimum and maximum values being maintained for only short times. Recording instruments show that this is quite characteristic during clear settled weather in Western Canada. There appears to be some regional difference in the time at which the maximum is reached. For example, at Saskatoon the highest relative humidity during August occurs usually at about 2 a.m., apparently about two or three hours earlier than at Winnipeg.

At the beginning of the period under discussion, the moisture content of the barley was about 20%. The sampling error was very high, no doubt owing to uneven ripening of the stand. Toward the end of the period, the sampling error of duplicates decreased greatly, but variations between consecutive samples remained fairly high, as can be seen in the results for August 21 (Fig. 8). *During this eight day period there was only one day during which the moisture content of the grain definitely followed the course of change of the relative humidity.* This was August 20. The weather on that day was distinguished from preceding days only by a slightly higher maximum temperature, 92.5° as against 89.9° the preceding day, and the highest average wind velocity for the period. On the whole, the moisture content either changed contrariwise to the humidity or was independent of it.

TABLE IX

SUMMARY OF WEATHER AT SASKATOON, AUGUST 8 TO AUGUST 20 INCLUSIVE, 1933

Factor	For the 13-day period	
	Range	Mean
Maximum temperature	75°–95°	84.5°
Minimum temperature	39°–62°	55°
Maximum relative humidity	75%–97%	88%
Minimum relative humidity	20%–43%	29%
Bright sunlight	4 hr.–13.9 hr.	11 hrs.
Wind velocity, m.p.h.		
8 a.m.	4–19.6	10.5
2 p.m.	7.1–15.8	10.7
8 p.m.	4.1–12.7	9.6

Another section of data suitable for studying the relation of relative humidity to moisture content of grain is the data in Table V for August 8–20 inclusive, at Saskatoon. This was a period of clear hot weather with moderate winds. Total recorded rainfall during the 13 days was 0.05 in. in two brief showers on August 9 and 15. A brief summary of the weather for this period is given in Table IX.

At the beginning of this period, 6 a.m. August 9, the moisture content of the wheat was 17.2%. At 12 noon August 10, it had definitely dropped to below 14.4%. By noon August 12 it was down to 12%. Thereafter samples were taken only three times daily, namely, at 6 a.m., 2 p.m. and 10 p.m. In order to facilitate discussion of these data, the moistures recorded for 6 a.m., 2 p.m. and 10 p.m. during the whole 12-day period have been retabulated in Table X.

The notes given in Table X under the heading "observations" were taken from a daily record of personal observations of the weather conditions, kept during the period of sampling in 1933. By this means one notes slight sprinkles of rain, too small to be recorded at the meteorological station, but large enough to affect the moisture of a sample of wheat collected soon afterwards.

It can be seen that there was little evidence of an increase in moisture from 2 p.m., the time of highest temperature and lowest humidity, to 10 p.m. when the relative humidity was increasing rapidly, owing to lowering of the

TABLE X

MOISTURES OF WHEAT RECORDED AT 6:00 A.M., 2:00 P.M. AND 10:00 P.M. AUGUST 8 TO 20, 1933, AT SASKATOON

Date	Moisture content at			Observations
	6 a.m. %	2 p.m. %	10 p.m. %	
August 9	17.2	15.2	16.4	Slight rain at 4–5:30 a.m.
10	14.1	13.2	13.0	
11	11.6	12.1	11.8	
12	12.0	no sample	11.6	
13	13.1	11.5	10.8	
14	11.1	10.5	9.9	Slight rain at 10:00 p.m.
15	11.3	10.9	10.6	Slight rain during night
16	11.2	11.0	11.1	
17	11.2	10.8	10.8	
18	10.6	10.3	10.1	
19	10.3	9.9	10.0	
20	10.8	10.4	13.4	Slight rain 6–8 p.m.
Mean—Aug. 11 to Aug. 20	11.3	10.8	{11.0 {10.7*	

* *Omitting Aug. 20.*

temperature. The high value, 13.4%, for August 20 is fully accounted for by the occurrence of a shower between 6 and 8 p.m. The 6 a.m. samples tended to be, on the average, about 0.6% higher in moisture content than those collected at 10 p.m. Two of the three increases greater than 1% are accounted for by showers occurring between the 10 p.m. and the 6 a.m. samplings.

At Edmonton, samples were collected at 2-hr. intervals during the period 6 a.m. Aug. 28 to 10 p.m. Aug. 31, and again during the period Sept. 11 to Sept. 14 inclusive. The moisture range of samples collected during the first period was 19 to 27.3% and during the second period it was 12 to 17.5%. The range of moisture of duplicate samples and the means, together with the relative humidity, hours of sunshine, and precipitation during these two periods, are shown graphically in Fig. 9.

The samples obtained during the first period, Aug. 28 to Aug. 31, were collected under conditions unfavorable for studying the effect of daily changes in relative humidity. On the first day, there were 13.5 hours of sunshine; the relative humidity decreased to 25 at 4 p.m. and then rose sharply to 85 by 12 p.m. This represented normal good harvest weather. The moisture content was lowest in the samples collected at midnight. The succeeding three days were overcast; no bright sunshine was recorded, and the relative humidity did not fall below 64%. The moisture content decreased during Aug. 29 and 30 to a minimum of about 19% at midday and then increased during the night. At noon Aug. 31, a rain of 0.66 in. fell and the moisture content increased to 26%, which was approximately the value at the beginning

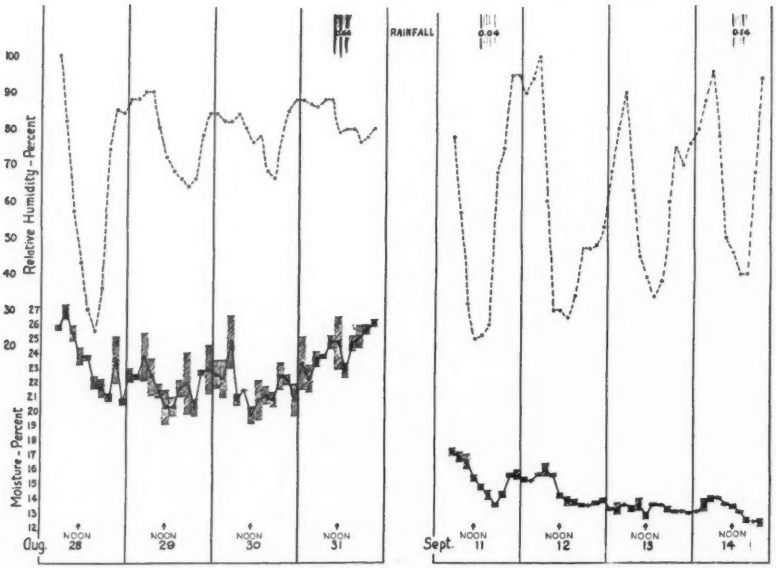

FIG. 9. *Upper and lower limits and average of moisture content of wheat samples collected at 2-hr. intervals for two 4-day periods at Edmonton in 1933.*

of the period. On the whole there seems to have been a rough correspondence between relative humidity and moisture content of the wheat during this 72-hr period.

The second four-day period, Sept. 11 to Sept. 14 inclusive, represented quite characteristic favorable harvesting weather, with bright days, wide ranges of relative humidity and temperature and little rain. The wheat at the beginning had a moisture content of about 17%, which decreased rapidly to 13.5% by 6 p.m. Sept. 11. Rainfall of 0.04 in. occurred between 12 noon and 4 p.m. over a period of three and one-quarter hours. This probably accounts for the increase of moisture content to about 15.5%. Thereafter the moisture content decreased to 13–13.5% and there was no further evidence of increase that could be attributed to changes of relative humidity. As in the results obtained at Winnipeg and Saskatoon, the wheat at Edmonton, having become dried to 13.5% or lower, showed little, if any, fluctuation of moisture content, despite the fact that the relative humidity increased each night to 90% or higher.

These data lead to the conclusion that in clear weather *the increase in relative humidity during the night causes at most only a small increase in moisture content of dry grain.* It cannot be gainsaid that grain just at 14.4% or slightly below this would likely be tough after a night in which the relative humidity rose to 90%, but without the intervention of other factors such as cloudy damp

weather and occasional sprinkles of rain, wheat does not remain at 14.4% moisture content during August in Western Canada, but tends rather to decrease to the range 10–12%.

On the basis of the data available, therefore, it seems safe to conclude that wheat, having decreased to below 14.4% in moisture content, stands little chance of becoming tough overnight in normal clear harvest weather, as a result of the increase in relative humidity. Little sprinkles of rain, too small to be recorded, even though of very brief duration, are likely to raise the moisture content of wheat much more rapidly than exposure to the high relative humidity of the night.

Rate of Drying Mature and Immature Wet Standing Grain

Rain during the late harvest season represents such a great hazard both to the farmer and the buyers of wheat that it is desirable to know something of the rates of wetting and drying of standing grain. As it is practically impossible to reproduce the conditions in the laboratory, information on this subject must be obtained in the field. Unfortunately, moderate to heavy rains are frequently followed by days of unsettled weather, during which drying is slow, and therefore it is extremely difficult to compare rates of drying of immature damp grain and mature damp grain. However, there can be selected from Tables III, IV and V several groups of data obtained under conditions that justify their use in comparing the rates of drying of immature and mature damp grain.

TABLE XI

COMPARISON OF RATES OF DRYING OF IMMATURE AND MATURE DAMP STANDING GRAIN

Mature				Immature			
Dates	Moisture range	Moisture decrease	Time, hr.	Dates	Moisture range	Moisture decrease	Time, hr.
Table III							
Aug. 26, 6 a.m. to Aug. 27, 12 a.m.	29.6% to 14.0%	15.6%	30	Aug. 14, 6 p.m. to Aug. 19, noon	28.3% to 13.6%	14.7%	114
Table IV							
Aug. 25, 9 a.m. to Aug. 26, 5 p.m.	29.2% to 14.0%	15.2%	32	Aug. 6, 5 p.m. to Aug. 9, 1 p.m.	28.3% to 13.1%	15.2%	68
Table V							
Sept. 2, 1 p.m. to Sept. 4, 5 p.m.	29.0% to 14.3%	14.7%	52	Aug. 4, 5 p.m. to Aug. 10, 5 a.m.	29.4%* to 14.1%	15.3%	132

* *During this period there was precipitation of 0.21 in. on Aug. 6 and 0.03 in. on Aug. 9.*

In Table XI there are given three sets of observations on the drying of damp mature standing grain and comparable data for immature grain. In all cases the data were selected for periods during which there was good drying weather.

It is impossible to make strict comparisons with immature and mature standing grain, because weather conditions cannot be accurately fixed by description and therefore the best that can be done is to make general observations. It seems reasonably certain that the weather during the early part of August, during which time the grain loses its initial moisture, is at least as favorable from the standpoint of drying as the weather following rains in late August and early September. Therefore, large differences in drying rates would likely have some significance.

It can be seen from the data in Table XI that in all cases cited the mature damp grain dries much more rapidly than the corresponding immature damp grain. The slowest rate with mature grain was sixteen hours faster than the fastest rate with immature grain.

With the data in hand it is impossible to make any rigid comparisons of the rates of wetting and of drying mature grain. The onset of rains often prevented sampling and when the rains started late in the afternoon, a period of eight to twelve hours frequently elapsed before the next sample was taken. All estimates of rate of wetting therefore tend to be low. The most pertinent data obtained in these investigations have been tabulated in Table XII.

TABLE XII

RATE OF WETTING STANDING GRAIN

Table	Place	Date	Hours	Time, hr.	Moisture, %			Precipitation, in.
					Initial	Final	Increase	
III	Winnipeg	Aug. 22 to Aug. 23	8 p.m. to 8 a.m.	12	11.1	31.2	20.1	1.22
IV	Saskatoon	Aug. 12	4 p.m. to 8 p.m.	4	12.7	25.9	13.2	0.8
IV	Saskatoon	Aug. 20	8 a.m. to 2 p.m.	6	12.5	27.8	15.3	0.1 (misty)
V	Saskatoon	Aug. 31	10 a.m. to 2 p.m.	4	15.2	23.0	7.8	0.65
V	Saskatoon	Sept. 10	8 a.m. to 8 p.m.	12	15.5	28.1	12.6	1.2
VII	Edmonton	Sept. 14 to Sept. 15	8 p.m. to 8 p.m.	24	12.4	26.4	14.0	0.88

Comparing these times with those for drying of mature grain in Table XI, it seems safe to conclude that the rate of wetting is very much faster than the rate of drying. This conclusion scarcely requires demonstration, because in wetting, the water comes in contact with the grain and is absorbed as liquid, whereas in drying the water has to be removed as vapor.

TABLE XIII

TEMPERATURE, HUMIDITY, SUNSHINE, RAINFALL AND WIND VELOCITY RECORD
(University of Manitoba, 1932)

Date	Temperature				Relative humidity				Sunshine, hr.	Rainfall, in.	Wind velocity, m.p.h.
	Max.	Hour	Min.	Hour	Max.	Hour	Min.	Hour			
Aug. 2	78	4 p.m.	67	8 p.m.	89	12 noon	39	4 p.m.	13.1	0.04	12.7
3	80	6 p.m.	65	8 a.m.	61	8 a.m.	30	6 p.m.	12.0	nil	11.6
4	76	12 noon	63	8 p.m.	69	8 p.m.	37	4 p.m.	8.8	0.06	10.3
5	72	2 p.m.	62	8 a.m.	86	8 a.m.	47	2 p.m.	7.0	trace	10.5
6	71	2 p.m.	57	8 a.m.	94	8 a.m.	49	2 p.m.	8.1	0.06	11.8
7	72	2 p.m.	61	8 a.m.	79	8 a.m.	52	12 noon	11.9	0.02	10.4
8	77	12 noon	63	8 a.m.	78	8 a.m.	41	2 p.m.	13.3	nil	7.1
9	82	4 p.m.	65	8 p.m.	58	10 a.m.	36	4 p.m.	14.0	nil	4.4
10	82	12 noon	67	8 a.m.	64	8 a.m.	37	2 p.m.	13.5	nil	5.9
11	82	2 p.m.	63	8 p.m.	67	8 a.m.	35	4 p.m.	12.1	nil	8.5
12	84	2 p.m.	66	8 a.m.	82	8 a.m.	30	4 p.m.	12.4	nil	10.9
13	86	4 p.m.	70	8 a.m.	66	8 a.m.	31	4 p.m.	10.9	nil	13.6
14	88	6 p.m.	78	8 a.m.	59	10 a.m.			8.9	0.03	10.8
15	89	12 noon	74	8 a.m.	61	10 a.m.	32	2 p.m.	12.8	nil	8.3
16	90	2 p.m.	70	8 a.m.	77	8 a.m.	31	4 p.m.	12.0	nil	9.2

TABLE XIV

TEMPERATURE, HUMIDITY, SUNSHINE, RAINFALL AND WIND VELOCITY RECORD
(University of Manitoba, 1933)

Rate	Temperature				Relative humidity				Sunshine, hr.	Rainfall, in.	Wind velocity, ave.
	Max.	Hour	Min.	Hour	Max.	Hour	Min.	Hour			
Aug. 9	87	2 p.m.	77.5	8 p.m.	53	8 p.m.	42	6 p.m.	13.0	0.06	10.7
10	76	4 p.m.	59.5	6 a.m.	89	10 p.m.	38	4 p.m.	12.7	—	11.8
11	79.5	noon	62.7	10 p.m.	74	10 p.m.	37	2 p.m.	12.5	—	15.2
12	70	4 p.m.	54.8	10 p.m.	100	6 a.m.	40	4 p.m.	13.1	—	11.6
13	75.2	4 p.m.	48.5	6 a.m.	100	6 a.m.	39	6 p.m.	13.8	—	9.2
14	85	4 p.m.	46.5	6 a.m.	100	6 a.m.	32	2 p.m.	13.8	—	5.8
15	89	2 p.m.	59	6 a.m.	65	12 p.m.	28	8 p.m.	3.7	0.02	8.7
16	80	2 p.m.	60	12 p.m.	95	6 a.m.	40	6 p.m.	9.6	—	14.3
17	69.5	4 p.m.	50.5	12 p.m.	93	12 p.m.	32	noon	10.3	—	13.9
18	76	4 p.m.	44.5	6 a.m.	100	6 a.m.	28	2 p.m.	12.5	—	5.6
19	89.8	2 p.m.	53	6 a.m.	75	6 a.m.	32	4 p.m.	12.2	—	14.5
20	92.5	4 p.m.	68	6 a.m.	67	6 a.m.	31	6 p.m.	12.7	—	18.6
21	80	4 p.m.	62.5	6 a.m.	89	6 a.m.	53	6 p.m.	1.6	—	12.0
22	80.5	4 p.m.	68	4 a.m.	81	10 a.m.	61	4 p.m.	4.7	1.22	9.8
23	78	6 p.m.	66	8 a.m.	100	8 a.m.	60	6 p.m.	6.3	.15	9.4
24	60.5	6 a.m.	60	8 a.m.	100	8 a.m.	—	—	—	.43	11.2
25	68.5	noon	59	6 p.m.	100	6 p.m.	58	noon	6.6	0.02	9.8
26	69	2 p.m.	47	6 a.m.	94	8 a.m.	51	2 p.m.	10.4	—	8.7
27	67	noon	63	8 a.m.	57	8 a.m.	48	10 a.m.	13.1	—	12.4

TABLE XV

TEMPERATURE, HUMIDITY, SUNSHINE, RAINFALL AND WIND VELOCITY RECORD
(University of Saskatchewan, 1932)

Date	Temperature				Relative humidity				Sunshine, hr.	Rainfall, in.	Wind velocity		
	Max.	Hour	Min.	Hour	Max.	Hour	Min.	Hour			4 a.m.	Noon	8 p.m.
Aug. 4	75	4 p.m.	52	12 p.m.	85	12 p.m.	31	2 p.m.	11.8	—	15.2	13.5	8.2
5	73	3 p.m.	46	5 a.m.	92	7 a.m.	29	1 p.m.	13.1	trace	12.6	10.5	6.7
6	75	6 p.m.	44	5 a.m.	95	12 p.m.	40	5 p.m.	11.5	—	8.6	7.5	2.2
7	83	4 p.m.	50	5 a.m.	96	6 a.m.	22	4 p.m.	14.3	—		4.1	9.2
8	89	6 p.m.	50	8 a.m.	80	8 a.m.	18	6 p.m.	14.2	—	4.8	13.6	15.7
9	92	4 p.m.	56	6 a.m.	72	4 a.m.	19	4 p.m.	14.0	—	11.8	17.0	19.7
10	91	4 p.m.	62	6 a.m.	69	6 a.m.	22	4 p.m.	10.4	—	23.2	15.6	18.7
11	70	11 a.m.	58	7 a.m.	96	12 p.m.	59	9 a.m.	0.5	—	21.8	21.1	13.8
12	78	3 p.m.	53	6 a.m.	100	5 a.m.	57	9 a.m.	7.6	0.04	9.3	3.8	4.6
13	78	4 p.m.	51	5 a.m.	97	3 a.m.	35	3 p.m.	13 4	0.75	8.6	6.8	6.3
14	78	3 p.m.	50	5 a.m.	94	5 a.m.	41	2 p.m.	14.1	—	12.8	9.0	5.2
15	83	5 p.m.	53	6 a.m.	94	6 a.m.	33	5 p.m.	13.3	—	4.8	6.6	4.2
16	77	2 p.m.	57	2 a.m.	91	6 a.m.	41	4 p.m.	11 9	trace	9.2	10.5	2.8
17	78	2 p.m.	45	4 a.m.	95	4 a.m.	27	2 p.m.	13.9	—	7.3	6.3	4.2
18	88	2 p.m.	50	3 a.m.	77	2 a.m.	30	2 p.m.	13.5	—	1.6	1.8	1.5
19	92	2 p.m.	54	5 a.m.	91	12 p.m.	30	2 p.m.	10.5	—	2.5	4.3	1.7
20	63	12 noon	55	12 p.m.	100	12 p.m.	82	8 a.m.	none	—	6.9	8.0	8.6
21	no record				100	5 a.m.			none	0.04	12.5	5.7	3.2
22	66	4 p.m.			97	12 p.m.			none	0.19	2.6	1.0	0.2
23	71	4 p.m.	57	8 a.m.	100	8 a.m.	70	2 p.m.	4.0	0.11		no record	
24	76	6 p.m.	60	7 a.m.	100	8 a.m.	60	6 p.m.	5.5	0.15	2.5	5.1	1.0
25	82	5 p.m.	51	7 a.m.	98	7 a.m.	36	3 p.m.	13.1	0.03		no record	
26	82	4 p.m.	52	6 a.m.	95	7 a.m.	30	4 p.m.	13.3	—	6.0	9.6	9.8
27	85	3 p.m.	51	7 a.m.	91	6 a.m.	25	2 p.m.	13.3	—	11.3	24.5	18.7

TABLE XVI

TEMPERATURE, HUMIDITY, SUNSHINE, RAINFALL AND WIND VELOCITY RECORD
(University of Saskatchewan, 1933)

Date	Temperature				Relative humidity				Sunshine, hr.	Rainfall, in.	Wind velocity		
	Max.	Hour	Min.	Hour	Max.	Hour	Min.	Hour			8 a.m.	2 p.m.	8 p.m.
Aug. 1	70	2 p.m.	34.5	4 a.m.	85	12 p.m.	28	2 p.m.	9.4	—	3.6	5.5	7
2	78	2 p.m.	50.5	2 a.m.	75	12 p.m.	27	2 p.m.	8.4	—	7	13.2	14
3	80.5	2 p.m.	50	4 a.m.	75	12 p.m.	29	2 p.m.	4.0	—	17.5	18.7	19.5
4	93	2 p.m.	60.5	3 a.m.	89	6 p.m.	22	10 a.m.	10.7	—	15	11.6	5.4
5	86.5	2 p.m.	56	1 a.m.	93	8 p.m.	30	12 noon	9.8	—	6.3	13.1	6.2
6	78.5	2 p.m.	53.5	6 a.m.	96	8 p.m.	39	12 noon	8.5	0.21	13.4	10.5	6.1
7	86	4 p.m.	51	2 a.m.	83	12 p.m.	25	12 noon	8.9	—	7.5	8	11.5
8	86	2 p.m.	58	5 a.m.	92	10 p.m.	25	2 p.m.	13.9	—	12.6	10.0	7.5
9	79	12 noon	53	10 p.m.	90	10 p.m.	22	6 a.m.	10.7	0.03	18.7	12.0	6.3
10	83.8	3 p.m.	50	4 a.m.	83	12 p.m.	26	12 noon	10.5	—	10.2	7.3	7.4
11	84	1 p.m.	57	10 p.m.	87	9 p.m.	33	12 noon	12.9	—	14.1	10.0	7.4
12	82.5	1 p.m.	54.5	2 a.m.	89	8 p.m.	39.5	12 noon	8.4	—	8.0	7.1	6.5
13	88.5	12 noon	54.5	2 a.m.	86	8 p.m.	30	12 noon	13.4	—	4.0	7.7	4.3
14	95	2 p.m.	56	2 a.m.	—	—	25	12 p.m.	13.1	—	5.6	15.8	6.8
15	86	4 p.m.	62	8 p.m.	89	11 p.m.	21	1 a.m.	11.8	0.02	10.8	12.5	9.0
16	75	4 p.m.	56	6 a.m.	97	10 p.m.	36	12 noon	12 3	—	19.6	10.7	—
17	77	4 p.m.	39	6 a.m.	90	12 p.m.	30	2 p.m.	11.2	—	4.0	15.0	12.7
18	92	4 p.m.	57.5	6 a.m.	75	12 p.m.	20	12 noon	11.2	—	12.4	12.9	11.6
19	84	4 p.m.	55.5	6 a.m.	93	10 p.m.	35	2 p.m.	4.0	—	6.3	9.2	6.3
20	85	2 p.m.	60	10 p.m.	91	12 p.m.	43	12 noon	10.0	—	10.7	8.5	4.1
21	74	4 p.m.	54.5	6 a.m.	91	12 p.m.	—	—	5.6	0.22	3.5	5.6	5.8
22	78.5	4 p.m.	43.5	6 a.m.	90	8 p.m.	23	12 noon	6.6	—	10.5	6.5	4.5
23	75	2 p.m.	59	10 p.m.	80	1 a.m.	41	12 noon	0.5	—	19.1	13.2	8.3
24	62.5	4 p.m.	52	10 p.m.	96	8 p.m.	61	2 p.m.	0.0	trace	8.8	8.3	4.5
25	70	2 p.m.	36.5	4 a.m.	84	4 p.m.	30	12 noon	13.7	0.02	8.2	7.0	7.7
26	80	2 p.m.	47	11 p.m.	96	6 p.m.	23	10 a.m.	12.7	—	9.8	8.3	0.5
27	75.5	1 p.m.	37	4 a.m.	75	11 p.m.	21	10 a.m.	13.6	—	2.7	8.3	10.2
28	83.4	3 p.m.	47	1 a.m.	80	12 p.m.	28	12 noon	13.1	—	16.6	13.5	11.0
29	85.4	2 p.m.	55.5	4 a.m.	92	10 p.m.	37	2 p.m.	13.2	—	9.1	5.6	8.1
30	88	3 p.m.	52.5	6 a.m.	95	12 p.m.	25	12 noon	10.0	—	6.3	10.5	9.2
31	69.5	1 a.m.	54	6 a.m.	100	2–12 p.m.	96	6 a.m.	0.0	0.01	6.1	8.0	12.0

TABLE XVI—*Concluded*

TEMPERATURE, HUMIDITY SUNSHINE, RAINFALL AND WIND VELOCITY RECORD
(University of Saskatchewan, 1933)

Date	Temperature				Relative humidity				Sunshine, hr.	Rainfall, in.	Wind velocity		
	Max.	Hour	Min.	Hour	Max.	Hour	Min.	Hour			8 a.m.	2 p.m.	8 p.m.
Sept. 1	57	12 noon	46.5	11 p.m.	100	noon	83	12 p.m.	0.0	0.65	23.0	30.0	25.2
2	59	2 p.m.	44.5	10 p.m.	95	8 p.m.	48	12 noon	4.5	0.55	20.0	10.1	6.7
3	62	2 p.m.	37	4 a.m.	85	10 p.m.	29	10 a.m.	12.6	—	3.6	14.2	21.5
4	82	2 p.m.	46	2 a.m.	75	12 p.m.	22	8 a.m.	10.8	—	3.6	14.2	21.5
5	63	3 p.m.	43.5	11 p.m.	95	12 p.m.	41	2 p.m.	8.5	—	12.2	12.7	12.1
6	48	4 p.m.	39.5	6 a.m.	100	8 p.m.	92	8 a.m.	0.0	0.21	11.6	8.6	8.6
7	52	2 p.m.	39.5	4 a.m.	97	2 a.m.	85	10 a.m.	0.0	0.02	7.2	5.6	5.5
8	72.5	2 p.m.	48	4 a.m.	90	9 p.m.	33	12 noon	9.9	—	11.8	10.7	7.1
9	80	2 p.m.	47	4 a.m.	89	8 p.m.	32	10 a.m.	12.7	—	2.3	6.6	8.8
10	66	6 a.m.	52.5	10 p.m.	98	8 p.m.	55	4 a.m.	0.0	—	10.5	8.6	5.6
11	67	6 p.m.	50	2 a.m.	97	12 p.m.	75	6 p.m.	2.5	1.2	3.2	5.8	2.1
12	63	2 p.m.	51	10 p.m.	100	10 p.m.	71	10 a.m.	0.3	0.002	4.1	5.3	7.5
13	61	4 p.m.	50	4 a.m.	100	2 a.m.	75	2 p.m.	3.1	—	13.5	16.7	24.7
14	65.5	4 p.m.	48	6 a.m.	92	2 a.m.	71	2 p.m.	7.2	—	31.7	27.7	24.1
15	60.5	1 a.m.	53.5	10 p.m.	100	2–12 p.m.	83	1 a.m.	0.0	—	19.8	13.5	7.1
16	59	4 p.m.	52.5	11 p.m.	96	8 p.m.	68	2 p.m.	10.3	0.1	15.6	9.6	6.5
17	69.5	2 p.m.	40	4 a.m.	86	8 p.m.	—	—	10.3	—	4.6	8.5	10.1
18	62.5	2 p.m.	48.5	6 a.m.	76	8 a.m.	67	6 p.m.	4.6	—	13.0	18.5	14.1

TABLE XVII

TEMPERATURE, HUMIDITY, SUNSHINE, RAINFALL AND WIND VELOCITY RECORD
(University of Alberta, 1932)

Date	Temperature				Relative humidity				Sunshine, hr.	Rainfall, in.	Average wind velocity, m.p.h.
	Max.	Hour	Min.	Hour	Max.	Hour	Min.	Hour			
Aug. 23	83	4 p.m.	46	8 a.m.	64	8 a.m.	22	4 p.m.	12.3	—	2.4
24	85	2–4 p.m.	58	8 a.m.	50	8 p.m.	20	4 p.m.	12.2	0.14	2.4
25	88	2 p.m.	59	8 a.m.	50	8 a.m.	20	2 p.m.	13.4	—	4.5
26	85	2 p.m.	66	8 a.m.	62	8 p.m.	39	2 p.m.	13.1	—	7.3
27	87	4 p.m.	62	8 a.m.	65	8 a.m.	32	4 p.m.	13.1	—	6.8
28	63	12 noon	55	8 p.m.	73	8 a.m.	47	12 noon	4.5	—	6.6
29	54	4 p.m.	49	8 p.m.	64	8 a.m.	31	4 p.m.	0.3	—	5.9
30	59	2 p.m.	46	8 a.m.	79	8 a.m.	21	4 p.m.	8.0	—	8.5
31	64	6 p.m.	34	8 a.m.	85	8 a.m.	49	4 p.m.	10.6	0.01	6.6
Sept. 1	61	4 p.m.	43	8 a.m.	100	6 p.m.	62	4 p.m.	6 0	0.02 (6 p.m.)	8.5
2	58	4 p.m.	45	8 a.m.	87	6 p.m.	55	12 noon	6.6	0.01 (4 p.m.)	11.4
3	65	4 p.m.	40	8 a.m.	71	8 p.m.	25	2 p.m.	8.4	—	4.7
4	72	6 p.m.	47	8 a.m.	75	8 a.m.	32	12 noon	8.8	—	4.6
5	79	4 p.m.	42	8 a.m.	79	8 p.m.	41	4 p.m.	11.6	—	2.8
6	83	2 p.m.	49	8 a.m.	70	8 a.m.	26	4 p.m.	9.6	—	4.3
7	80	2 p.m.	65	8 p.m.	84	8 p.m.	42	2 p.m.	11.5	—	5.7
8	61	8 a.m.	55	2 p.m.	rain					0.13 (4 p.m.)	16.2
9	73	2 p.m.	51	8 p.m.	42	4 p.m.	88	8 p.m.	11.4	—	6.2
10	79	12 noon	64	8 p.m.	65	8 p.m.	28	12 noon	11.2	—	11.6
11	64	8 a.m.	44	8 p.m.	87	8 p.m.	47	12 noon	2.3	Trace	7.8
12	61	2 p.m.	53	8 p.m.	81	8 p.m.	44	12 noon	6.8	—	4.4
13	78	4 p.m.	48	8 a.m.	67	8 a.m.	20	12 noon	8.6	—	8.6
14	61	2 p.m.	53	8 p.m.	81	8 p.m.	41	12 noon	10.7	—	17.0

TABLE XVIII

TEMPERATURE, HUMIDITY, SUNSHINE, RAINFALL AND WIND VELOCITY RECORD
(University of Alberta, 1933)

Date	Temperature				Relative humidity				Sunshine, hr.	Rainfall, in.	Wind vel., ave.
	Max.	Hour	Min.	Hour	Max.	Hour	Min.	Hour			
Aug. 19	76	2 p.m.	59	10 p.m.	96	10 p.m.	58	2 p.m.	7.9	0.02	9.0
20	73	6 p.m.	50	6 a.m.	90	10 p.m.	36	2 p.m.	6.1	—	5.2
21	84	2 p.m.	45	6 a.m.	90	10 p.m.	27	noon	13.9	—	5.0
22	92	2 p.m.	46	6 a.m.	100	6 a.m.	32	2 p.m.	13.3	0.27	5.0
23	62	noon	52	10 p.m.	100	6 a.m.	60	4 p.m.	0.9	0.17	6.7
24	72	2 p.m.	44	6 a.m.	100	6 a.m.	38	noon	13.3	—	4.0
25	80	2 p.m.	36	6 a.m.	100	6 a.m.	30	2 p.m.	13.9	—	4.0
26	76	2 p.m.	34	6 a.m.	100	6 a.m.	30	4 p.m.	13.5	—	4.4
27	82	4 p.m.	43	6 a.m.	93	6 a.m.	24	2 p.m.	13.5	—	8.6
28	90	4 p.m.	46	6 a.m.	100	6 a.m.	24	4 p.m.	13.5	—	4.7
29	61	6 p.m.	46	6 a.m.	100	6 a.m.	64	6 p.m.	—	—	5.4
30	58	4 p.m.	50	10 p.m.	85	10 p.m.	66	6 p.m.	—	—	2.6
31	54	10 a.m.	50	2-10 p.m.	88	10 a.m.	76	6 p.m.	—	0.66	8.7
Sept. 1	62	2 p.m.	50	8 a.m.	96	8 a.m.	58	6 p.m.	4.0	—	12.9
2	68	4 p.m.	38	6 a.m.	100	6 a.m.	33	4 p.m.	12.0	—	6.6
3	69	6 p.m.	39	6 a.m.	100	6 a.m.	39	4 p.m.	8.4	—	8.8
4	60	2 p.m.	46	6 a.m.	100	6 a.m.	50	2 p.m.	7.8	—	9.2
5	41	4 p.m.	33	6 a.m.	100	6-12 a.m.	88	6 p.m.	—	0.07	5.0
6	44	2 p.m.	36	6 a.m.	100	6-10 p.m.	89	6 a.m.	—	0.09	2.7
7	62	4 p.m.	42	6 a.m.	98	8 a.m.	55	4 p.m.	3.1	—	3.0
8	82	2 p.m.	40	6 a.m.	100	6 a.m.	30	2 p.m.	9.5	—	5.7
9	89	4 p.m.	43	6 a.m.	100	6 a.m.	23	2 p.m.	11.9	—	3.4
10	67	4 p.m.	53	6 a.m.	90	10 p.m.	57	noon	1.8	0.05	3.7
11	70	2 p.m.	38	10 p.m.	95	10 p.m.	22	noon	10.0	0.04	4.0
12	71	2 p.m.	34	6 a.m.	100	6 a.m.	28	2 p.m.	7.4	—	9.4
13	73	2 p.m.	40	6 a.m.	90	6 a.m.	34	2 p.m.	7.1	—	5.4
14	75	2 p.m.	47	6 a.m.	98	10 p.m.	40	2 p.m.	5.8	0.14	5.6
15	53	10 a.m.	47	10 p.m.	98	6 p.m.	94	2 p.m.	—	0.64	8.0
16	57	2 p.m.	41	10 p.m.	93	6 a.m.	46	2 p.m.	8.0	0.21	13.7

Conclusion

In applying the information obtained in this study to the problem of avoiding tough grain in straight combining, the following general observations may be made.

Under the most favorable weather conditions, four to seven days must elapse from the time grain is fit to cut with the binder until it can be harvested by straight combining to obtain straight grade grain. Mature grain usually dries to 11–13% moisture content in areas having favorable harvest weather, and thereafter there is practically no danger of the moisture rising above 14.4% during the night, except through the occurrence of rains or mists or protracted periods of damp cloudy weather. The "toughness" that normally occurs at night during clear weather has to do with the decrease in brittleness of the straw, rather than with increase of moisture of the wheat. Rains, even though of brief duration, cause a very rapid increase in moisture content of dry wheat. Increases of from 12.7% to 26% in no more than four hours

have been observed. The subsequent drying is much slower than the wetting. It might be expected that at least 24 hours of the most favorable weather would be required to reverse a change such as that noted above. This is likely to lead to an error in judgment on the part of combine operators, which will result in tough grain being threshed, because the straw becomes brittle and fit for threshing before the moisture of the grain has decreased to below the "tough" limit.

References

1. COLEMAN, D. A. and FELLOWS, H. C.—Cereal Chem. 2 : 275–287. 1925.

QUALITY AND KEEPING PROPERTIES OF FLOUR FROM WHEAT GROWN ON THE BLACK AND GRAY SOILS OF ALBERTA[1]

By O. S. Aamodt[2] and A. G. McCalla[3]

Abstract

Weight per bushel and milling yields of hard red spring wheats grown on the black soil at Edmonton were the same as for the same varieties grown on the gray soil at Fallis. Grade, protein content and baking quality of Edmonton grown samples were superior. The flour from most of the Edmonton grown samples retained its quality for at least two years after milling, but flour from most of the Fallis grown samples had deteriorated so much during 10 months storage that it was unfit for breadmaking. Flour from Reward showed less deterioration than that from any other standard variety grown at Fallis. It also had the best original baking quality, and is the only one of the recommended varieties considered satisfactory for the gray soil area.

Introduction

The gray wooded soil belt which occupies a large proportion of western and northern Alberta is sparsely settled at the present time, but, because of favorable moisture conditions, the trend of settlement is toward this area. Much of the soil is relatively low in fertility and requires special management if satisfactory results are to be obtained (9). Only recently have experimental plots been established on these soils, the early work being carried out by the Department of Soils of the University of Alberta. This work has been concerned with the fertility and management of the soil rather than with the quality of the products.

During the past few years the Department of Field Crops of the University of Alberta has located experimental plots at Fallis, a point 50 miles west of Edmonton. The nature and composition of the gray soil in this area, and of the black loam soil typical of the Edmonton district are described by Wyatt, Newton and Mather (10). The soil at Fallis is a wooded podsolic loam which forms the main class of well drained soil found in wooded areas. The quality of wheat grown at Fallis is probably fairly typical of that for the wheat grown in the gray soil belt as a whole.

This paper deals with the results obtained in a study of the quality of wheat grown at Edmonton and Fallis in 1932 and 1933.

Materials and Methods

The material used in this study was grown in replicated rod row plots at Edmonton and Fallis, in connection with the routine testing of hard red spring wheat standard varieties and hybrids. The quality of each of the named varieties Garnet, Huron, Marquis, Red Bobs 222 and Reward has

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been discussed by Malloch, Geddes and Larmour (6), who concluded that Reward, Marquis and Red Bobs 222 were satisfactory for export and domestic milling. Garnet and Huron were both considered inferior to Marquis in baking quality. Caesium is a Russian wheat obtained from Dr. Talanov of the West Siberian Experimental Station in 1928. It is usually inferior to Marquis in protein content and baking quality. The hybrids I-28-60 and I-28-65 are selections made from a Marquillo × Marquis-Kanred cross introduced from the Minnesota Experimental Station. Both are satisfactory in protein content and in milling and baking quality.

All samples were graded at the Edmonton office of the Western Grain Inspection Division. Average grades were calculated by assigning numerical values of from 0 to 4 to Grades 1 Hard, 1, 2, 3 and 4 Northern respectively. This method has been used by Larmour, Geddes and Cameron (5).

Nitrogen was determined by the Kjeldahl method with mercuric oxide as catalyst. Protein values are reported as total nitrogen × 5.7, and corrected to a 13.5% moisture basis.

Milling tests were carried out on an experimental mill following the flow sheet presented by Geddes (3). Straight flour was produced in all tests.

The baking results reported were obtained using the bromate formula with 1 mg. of potassium bromate per loaf (2). The simple formula was also used in 1932, and the malt-phosphate-bromate in 1933, but the results obtained with these formulas led to essentially the same conclusions as those obtained with bromate, so they are not included in the tables.

Results

Miscellaneous and Milling Tests

The results of miscellaneous and milling tests are presented in Table I.

Edmonton grown samples averaged about 1.5 grades higher than Fallis grown in both years, although the average for 1933 samples from each place was about one grade lower than for 1932 samples. There was a marked difference in the effect of soil on the grade of different varieties. Reward and Garnet showed the least tendency for grade reduction when grown on the gray soil, but since by regulation of the Grain Inspection Division, 2 Northern was the highest grade which could be granted Garnet, the results for this variety do not necessarily indicate that there were no differences in the external characteristics of the samples.

Individual differences in weight per bushel cannot be regarded as significant. The maximum difference between Edmonton- and Fallis-grown samples of the same variety was 2.5 lb.; but the differences in some varieties favored one, and in others the other, sample.

The protein content of Fallis grown samples was lower than that of Edmonton grown for each variety, although there were varietal differences in the degree of variation. The average protein content of Edmonton grown samples was 3.4% higher in 1932, and 4.0% higher in 1933, than that of

TABLE I

COMPARISON OF QUALITY OF WHEAT GROWN AT EDMONTON AND FALLIS

Variety	Grade*		Wt. per bushel, lb.		Protein, %		Yield of straight flour, %		Loaf volume, cc.		Partial baking score	
	Edmonton	Fallis	Edmonton	Fallis	Edmonton	Fallis	Edmonton	Fallis	Edmonton	Fallis	Edmonton	Fallis
1932												
Caesium	2°	3°	67	65.5	14.0	11.0	69.1	70.6	672	622	57	53
Garnet	2°	2°	63.5	65	14.1	11.8	70.1	67.3	648	618	54	52
Huron	1°	2°	64	63.5	14.6	11.1	69.2	70.5	670	586	54	54
Marquis	1 Hard	2°	64.5	65	15.2	11.0	70.0	73.1	721	600	52	51
Red Bobs	1 Hard	3°	64	64	14.2	10.3	70.6	71.8	632	588	57	52
Reward	1 Hard	1 Hard	64.5	67	16.5	13.6	69.1	72.3	708	662	55	57
Av. of 18	0.9	2.3	64.3	64.3	14.9	11.5	69.0	69.6	703	619	54	53
1933												
Caesium	2°	4°	67	66	16.0	11.1	71.4	70.5	730	603	44	36
Garnet	2°	2°	65.5	65.5	14.1	11.7	70.8	69.8	672	588	53	43
Huron	2°	4°	65	65	15.1	10.4	72.2	69.0	663	558	58	36
Marquis	1°	4°	66	65	15.3	10.7	69.8	69.5	660	548	56	41
Red Bobs	1°	3°	66	64.5	14.7	10.6	71.4	71.6	694	632	53	45
Reward	1°	2°	66	67	16.8	12.6	68.2	68.1	795	627	59	51
Ave. of 11	1.9	3.4	65.5	65.2	15.2	11.2	70.2	69.6	696	603	53	42

**1° = No. 1 Northern; 2 = No. 2 Northern, etc.*

the Fallis grown. The results obtained in this study represent fairly well the relative differences in protein content of samples grown in the black and gray soil areas.

Individual differences in milling results, like those in weight per bushel, cannot be considered significant. The average flour yields from samples grown at both places in both years were practically the same.

Baking Tests Made One Month after Milling

The first baking tests were made approximately one month after the wheat was milled. The loaf volume and the partial baking score (1) results are presented in Table I.

For both years the loaf volume of each individual Edmonton grown sample was larger than that of the comparable Fallis grown sample. The average volume of loaves from Edmonton-grown material was about 90 cc. greater than the average of those from the Fallis grown. The results for the two years are essentially the same, and show that the differences are probably to be expected in any comparison of material from the two places.

The partial baking scores of the two groups of samples collected in 1932 were similar, but those for the 1933 samples show a marked superiority of Edmonton grown material. There were decided varietal differences in 1933 among Fallis grown samples, the distinct superiority of Reward and inferiority of Caesium and Huron being outstanding. Reward was the only variety which could be considered of satisfactory quality when grown at Fallis, and it was distinctly inferior to the Edmonton grown sample of the same variety.

Correlation studies on these and similar samples have been made by Aamodt and Torrie (1). These studies showed that loaf volume and protein content were more closely correlated for Fallis grown than for Edmonton grown material. This was to be expected because the general level of protein content of Fallis grown samples was low and in the range where differences are most important in their effect on loaf volume. The same relation was found for the correlations between partial baking score and protein, but partial correlations showed that protein content was more closely related to loaf volume than to partial baking score.

Baking Tests Made Ten Months after Milling

Fifteen of the original 18 pairs of samples grown in 1932 were re-baked approximately ten months after milling. The flour had been stored in cans with fairly close fitting tops, so that the moisture loss during storage was not over 1%, and at the time of the second baking the moisture content of the samples was between 11 and 12%. Unfortunately most of the flour from Reward and Marquis samples had been used for other purposes, so these varieties could not be included in the second test. The results obtained, together with those for the original baking, are presented in Table II.

These results show that, while the flour from the Edmonton samples made just as good bread after ten months' storage as after one month, that from some of the Fallis samples had deteriorated badly. There was considerable

TABLE II

BAKING RESULTS OF FLOUR SAMPLES FROM EDMONTON AND FALLIS WHEAT

Variety	Origin	Loaf volume, c.c			Partial baking score		
		Stored 1 mo.	Stored 10 mo.*	Change after 10 mo.* storage	Stored 1 mo.	Stored 10 mo.*	Change after 10 mo.* storage
1932							
Caesium	Edmonton	672	729	57	57	54	− 3
	Fallis	622	459	−163	52	37	−15
Garnet	Edmonton	648	592	− 56	54	54	0
	Fallis	618	392	−226	52	32	−20
Huron	Edmonton	670	637	− 33	54	54	0
	Fallis	586	572	− 14	54	48	− 6
I-28-60	Edmonton	770	782	12	52	56	4
	Fallis	650	364	−286	57	31	−26
I-28-65	Edmonton	695	728	33	58	57	− 1
	Fallis	638	590	− 48	55	54	− 1
Red Bobs	Edmonton	632	666	34	57	55	− 2
	Fallis	588	428	−160	52	39	−13
Average of 15	Edmonton	694	700	6	54	54	0
	Fallis	617	503	−114	53	41	−12
1933							
Garnet	Edmonton	672	456	−216	53	46	− 7
	Fallis	588	414	−174	43	33	−10
Marquis	Edmonton	660	610	− 50	56	56	0
	Fallis	548	473	− 75	41	45	4
Red Bobs 222	Edmonton	694	624	− 68	53	58	5
	Fallis	632	440*	−192	45	33	−12
Reward	Edmonton	795	644	−151	59	58	− 1
	Fallis	627	586	− 41	51	51	0

**1933 samples stored 12 months.*

variation in the varietal reaction with respect to the deterioration. The two selections I-28-60 and I-28-65 represent the extremes, the former showing a decrease of 286 cc. in loaf volume, and a reduction of 26 in partial baking score, and the latter a decrease of 48 cc. in volume, and a reduction of 1 in baking score. One hybrid showed an increase of 18 cc. in loaf volume but a slight decrease in baking score.

The loaves baked from badly deteriorated flour were poor in all respects. They were dull in crust color, rough in form, coarse and soggy in texture, and dark in crumb color. These characteristics were most marked in the poorest loaves, and the extent to which they appeared was roughly proportional to the decrease in loaf volume.

Flour from some of the varieties was baked 15 months after milling, and the relations obtained after ten months' storage were still found to hold.

Although there was insufficient flour from Reward and Marquis samples to bake a second time, there was sufficient to use in gluten tests. Preliminary studies on deteriorated and normal samples of flour showed that the gluten of deteriorated flour was hard to wash out, and when obtained was coarse, spongy, and dark in color, while that from non-deteriorated flour was easy to wash out and was coherent, elastic and creamy. The Edmonton- and Fallis-grown Reward and the Edmonton grown Marquis yielded normal gluten, but the Fallis grown Marquis appeared to be badly deteriorated.

The 1933 samples were re-baked twelve months after milling. In general the results (Table II) substantiated those obtained with the 1932 samples, but several differences must be noted.

There were decreases in the volumes of the loaves baked from both Edmonton- and Fallis-grown samples, and in the case of Garnet and Reward,

Baked after 1 month's storage. *Baked after 12 months' storage.*

FIG. 1. *The effect of storage on the baking quality of flour, 1933 samples.*

these decreases were greater for Edmonton- than for Fallis-grown. The loaf volumes of Edmonton grown Marquis, Red Bobs 222 and Reward, and Fallis grown Reward, however, were still large enough to be considered satisfactory, and the partial baking scores indicate that real deterioration of quality had not taken place. Fallis grown Marquis was lower in loaf volume than is satisfactory for this type of wheat, and the apparent improvement in partial baking score was due to an abnormally high absorption of water. When allowance was made for this the score was lower than for the first baking. Fallis grown Garnet and Red Bobs were definitely deteriorated, as indicated by marked decreases in both loaf volume and partial baking score, (Fig. 1).

Taking into consideration the lower average level of original quality in the Fallis samples, these results substantiate those obtained for the 1932 samples. Fallis-grown Reward deteriorated little during storage, Marquis deteriorated somewhat more, while Garnet and Red Bobs 222 deteriorated markedly. The deterioration of Edmonton grown Garnet has not been observed before, but emphasizes the necessity of studying this problem further. It was the only standard variety showing this effect although one of the selections gave similar results.

Discussion

The significance of the general low quality of the wheat produced on the gray soil at Fallis in 1933 can hardly be over-emphasized. If the quality of the wheat grown in other parts of the gray soil area is in general as low as in these samples, it is certain to militate against the maintenance of high quality in western Canadian wheat. The annual protein surveys (4) carried out by the Grain Research Laboratory of the Board of Grain Commissioners at Winnipeg show definitely that in many parts of the gray soil area the protein level of the wheat grown is lower by as much as 2 or 3% than that of the Fallis grown samples. Few of the samples obtained from the gray soil belt were much higher in protein than those included in the present study.

It has been shown further that, although yields from the gray soil may be materially increased by the use of fertilizers and green manures (8, 9), protein content of the grain produced is usually not increased, but is actually reduced in many cases (7). While the growing of legumes and the use of fertilizers appear necessary to the proper management of the gray soil, so far there has been no indication that the quality of wheat is materially improved by such management.

Of even greater importance, however, is the fact that the flour produced from many of the standard varieties of wheat grown at Fallis, will not keep when stored under the same conditions as flour milled from the same varieties grown on black soil, although the latter have kept satisfactorily for over two years. Whether the flour from wheat grown in other districts in the gray soil area deteriorates during storage has not been determined, but this point is under investigation at present. The effect of fertilizers on the keeping

quality of flour has not been investigated yet, but fundamental studies on the nitrogen and mineral nutrition of wheat grown on both soils are being carried out.

It is important to recognize that the flour from some varieties is apparently not subject to deterioration even after storage for 15 months after milling. At the present time the varieties Garnet, Red Bobs 222, Reward and Marquis are the most commonly grown in the area under discussion. The results of this study indicate that Reward is the most satisfactory in original quality, this quality being high enough to justify the production of the variety in the gray soil area. Fallis grown Reward also appears to be less deleteriously affected by storage than the other standard varieties, and is the only one of the varieties commonly recommended for central and northern Alberta which should be grown on the wooded soils.

Little commercially milled flour is likely to be stored for as long as a year, and commercial storage practices are probably less favorable to the processes of deterioration than those used in the laboratory. The question of deterioration may, however, assume more than academic importance if the volume of wheat from the area under discussion is increased by continued expansion of development in this area.

The results so far reported have all pertained to the study of stored flour. Much of the grain is stored as such for longer periods than it is stored as flour, and this fact has led to a study of the effect of storage on wheat as well as flour. Preliminary results indicate that wheat stored for 15 months after the first milling exhibits little if any of the signs of deterioration exhibited by the flour.

Studies on the chemical changes involved in the deterioration, and on the physiological development of wheat grown on the two soils are being carried out by the junior author and his associates. The results of these studies will be published later.

References

1. AAMODT, O. S. and TORRIE, J. H. Can. J. Research, C, 13 : 79-88. 1935.
2. AITKEN, T. R. and GEDDES, W. F. Cereal Chem. 11 : 487-504. 1934.
3. GEDDES, W. F. Can. J. Research, 1 : 528-558. 1929.
4. GEDDES, W. F. Seventh protein survey of western Canadian hard red spring wheat, 1933 crop. Winnipeg, 1934.
5. LARMOUR, R. K., GEDDES, W. F. and CAMERON, D. Can. J. Research 9 : 486-501. 1933.
6. MALLOCH, J. G., GEDDES, W. F. and LARMOUR, R. K. Can. J. Research 6 : 333-361. 1932.
7. MCALLISTER, R. E. Sci. Agr. 14 : 249-256. 1934.
8. WYATT, F. A. Sci. Agr. 14 : 327-335. 1934.
9. WYATT, F. A. and NEWTON, J. D. Univ. Alberta Coll. Agr. Bull. 21. 1932.
10. WYATT, F. A., NEWTON, J. D. and MATHER, T. H. Univ. Alberta, Coll. Agr. Bull. 20. 1930.

SUPERIORITY OF SILVER NITRATE OVER MERCURIC CHLORIDE FOR SURFACE STERILIZATION IN THE ISOLATION OF *OPHIOBOLUS GRAMINIS* SACC.[1]

By F. R. Davies[2]

Abstract

It has been difficult to isolate *Ophiobolus graminis* from plant parts previously surface sterilized by the commonly used mercuric chloride method, although *Helminthosporium sativum* and *Fusarium* spp. are readily isolated following its use. When a silver nitrate method of surface sterilization was substituted, *O. graminis* was isolated with considerably more success than had previously been obtained. These results can be explained by the difference in reaction of the above-mentioned fungi to these chemicals. When similar concentrations of these chemicals were added to nutrient agar, silver nitrate proved less toxic to *O. graminis* than mercuric chloride, whereas the reverse was true for *H. sativum*.

Introduction

In studies on the parasitism of cereal foot- and root-rotting fungi, difficulty was encountered in isolating *Ophiobolus graminis* Sacc. from plant tissue known to be infected. It occurred to the writer that this might be due to mercuric chloride, the surface sterilizing agent used, especially since it is known that certain chemicals have a differential toxicity to different species of fungi.

Mercuric chloride has been found quite satisfactory in the isolation of *Helminthosporium sativum* P. K. and B. and *Fusarium* spp., but when used on material containing *Ophiobolus graminis* and other organisms, the latter usually overgrew the relatively slow growing *O. graminis*.

Apparently other workers have encountered similar difficulty. Broadfoot (2) reports inability to isolate *Ophiobolus graminis* from naturally infected material from the field; he found that other organisms, such as *Helminthosporium sativum* and *Fusarium* spp., grew to the exclusion of *O. graminis*, even though the latter had caused most of the damage. Similarly, Russell (9) reports his invariable failure to isolate *O. graminis* from diseased tissue.

Because of the difficulties mentioned above, it was the purpose of this investigation to find a suitable method of isolating *Ophiobolus graminis* from diseased plant tissues and to explain the unsuitability of mercuric chloride for surface sterilization.

Relative Values of Different Methods of Surface Sterilization in the Isolation of *Ophiobolus graminis* from Plant Tissues

Methods

The material used for the preliminary tests consisted of young wheat stems from plants with pronounced "take-all" symptoms, growing in soil that had been infested with *Ophiobolus graminis*. For the subsequent comparison of mercuric chloride and silver nitrate the material consisted of wheat stubble from plants naturally infected in the field.

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Contribution from the Department of Field Crops, University of Alberta, with financial assistance from the National Research Council of Canada. Taken from a thesis submitted in partial fulfilment of the requirements for the degree of Master of Science.

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Several methods which had previously been used by others for the surface sterilization of seeds were tried. These involved the use of such chemicals as silver nitrate, calcium hypochlorite, and hydrogen peroxide. In addition, a method of washing in sterile water, devised by Simmonds (10), was tried. The results are summarized in Table I. The general method of procedure

TABLE I

THE EFFECT OF VARIOUS CHEMICALS, USED FOR SURFACE STERILIZATION, ON THE SUBSEQUENT ISOLATION OF *Ophiobolus graminis* FROM INFECTED WHEAT PLANTS

Surface sterilizing agent	Concentration	Time of immersion, min.	Rinsing agent	Isolations*
Mercuric chloride	1 : 1,000	2	70% ethyl alcohol	1
	1 : 2,000	2	70% ethyl alcohol	0
	1 : 1,000	2	Sterile water	0
Silver nitrate	1 : 100	2	Sterile sodium chloride and sterile water	4
	1 : 100	5	Sterile sodium chloride and sterile water	3
Calcium hypochlorite	1 : 14	2	Sterile water	0
	1 : 14	5	Sterile water	0
Hydrogen peroxide	3 : 100	2	Sterile water	0
	3 : 100	5	Sterile water	0
None	—	5	Washing in sterile water (Simmonds' method)	0

**Indicates the number of isolations from 12 pieces of infected stems plated.*

was as follows. The tissues were cut up into pieces approximately 5 mm. long; these were immersed in the various solutions for varying lengths of time, and then washed in alcohol, sterile sodium chloride, or sterile water, as indicated in Table I; the pieces were then placed on potato-dextrose agar in petri dishes and incubated at room temperature.

Results

Ophiobolus graminis was isolated only when silver nitrate and mercuric chloride were used for surface sterilization (Table I). To ascertain which was preferable, a more extensive test was made with ten samples of wheat

TABLE II

THE EFFECT OF MERCURIC CHLORIDE AND SILVER NITRATE, USED FOR SURFACE STERILIZATION, ON THE SUBSEQUENT ISOLATION OF *Ophiobolus graminis* FROM INFECTED WHEAT PLANTS

Specimen No.	Number of isolations*		Specimen No.	Number of isolations*	
	Mercuric chloride	Silver nitrate		Mercuric chloride	Silver nitrate
2	1	1	141	0	0
23	0	1	191	0	5
73	0	4	201	1	6
88	0	0	247	0	2
126	0	1	292	1	8
			Total	3	28

**Indicates the number of isolations from 12 pieces of infected stem from each specimen.*

stubble that showed typical "take-all" symptoms when collected in Alberta during 1930 and 1931. Twenty-four pieces of diseased stems were cut from each sample, 12 were treated with mercuric chloride and 12 with silver nitrate. Results are given in Table II.

A summary of the results given in Table II shows that *Ophiobolus graminis* was isolated from only three out of the ten samples treated with mercuric chloride, that is from only 3 of the 120 pieces of stubble. On the other hand, it was isolated from 8 of the 10 samples or from 28 of the 120 pieces of stubble treated with silver nitrate.

A third series of isolations made in a similar manner resulted in seven isolations after the use of silver nitrate and only one after using mercuric chloride. Table III summarizes the results obtained from the three series.

TABLE III

SUMMARY OF THE RESULTS OF THREE SERIES OF TESTS ON THE EFFECT OF MERCURIC CHLORIDE AND SILVER NITRATE, USED FOR SURFACE STERILIZATION, ON THE SUBSEQUENT ISOLATION OF *Ophiobolus graminis* FROM INFECTED WHEAT PLANTS

Series	Silver nitrate method		Mercuric chloride method	
	Number of isolations*	Isolation, %	Number of isolations*	Isolation, %
1	7/24	29.3	1/36	2.8
2	28/120	23.3	3/120	2.5
3	7/75	9.3	1/75	1.3
Total	42/219	19.2	5/231	2.2

**Numerator of each fraction indicates the number of pieces of infected stems yielding Ophiobolus graminis, while the denominator indicates the number plated.*

The results given in Table III show a large difference in favor of the silver nitrate method, and from the consistency of the results it seems quite safe to recommend silver nitrate in preference to mercuric chloride as a surface sterilizing agent for the isolation of *Ophiobolus graminis* from diseased wheat stems.* By this method it has been found possible to isolate *O. graminis* from wheat stems several years old. It has also been used in the isolation of this fungus from the dead stems of other grasses and also from living root and stem tissues.

Relative Toxicity of Mercuric Chloride and Silver Nitrate to *Ophiobolus graminis* and *Helminthosporium sativum*

Many investigations have shown that the toxicity of certain chemicals to fungi and bacteria varies greatly with the organism, the differences being so great as to form a basis for differentiation between certain species (6, 7).

**Since this section of the work was completed Mead (8) has published some studies of methods of treating diseased wheat roots and seeds for the isolation of fungi. He included silver nitrate in his study. However, owing to variations in technique employed, his results are not strictly comparable with those reported here.*

Coons and Strong (4) found that certain fungi were capable of growing in concentrations of copper sulphate which were decidedly toxic to other fungi. Link (7) was able to differentiate between *Fusarium oxysporum* Schlecht and *F. trichothecioides* Woll. by the use of certain organic acids as growth inhibiting substances in the media on which the two fungi were grown. Leonian (6) showed that species of *Phytophthora* differ in their ability to grow in media containing different concentrations of Malachite green, and Hotchkiss (5) found varying responses in the growth of bacterial cultures on media to which the chlorides of various cations had been added. Similarly, Bateman (1) found that *Fomes annosus* (Fr.) Cooke was more sensitive to mercuric chloride than to silver nitrate.

Having demonstrated that the chance of success in isolating *Ophiobolus graminis* was far greater when silver nitrate was used as a surface sterilizing agent than when mercuric chloride was used, and having observed that the latter chemical could be used successfully in the isolation of *Helminthosporium sativum*, the writer believed that the explanation might be found in the relative toxicity of these chemicals to the fungi in question. Consequently experiments were made to determine the effects of these chemicals in dilute concentrations on the growth rates of these fungi on artificial media.

To determine the relative toxicity of mercuric chloride and silver nitrate to *Ophiobolus graminis* and *Helminthosporium sativum* the fungi were grown in petri dishes on potato-dextrose agar containing the chemicals in concentrations ranging from 1 : 1,000 to 1 : 50,000. The diameters of the colonies were measured after five days' growth at room temperature. The results are given in Table IV and illustrated in Figs. 1 and 2.

It is evident that mercuric chloride is much more toxic to *Ophiobolus graminis* than to *Helminthosporium sativum*. This in itself might offer an explanation of the difficulty of isolating *O. graminis* from tissue previously surface

TABLE IV

EFFECT OF MERCURIC CHLORIDE AND SILVER NITRATE ON THE GROWTH OF *Ophiobolus graminis* AND *Helminthosporium sativum* ON NUTRIENT AGAR

Concentration of chemical added to the media	Diameters of colonies*							
	In mm.				In per cent of check			
	Silver nitrate		Mercuric chloride		Silver nitrate		Mercuric chloride	
	O. gram.	*H. sat.*	*O. gram.*	*H. sat.*	*O. gram.*	*H. sat.*	*O. gram.*	*H. sat.*
Check	30	64	24	67	100	100	100	100
1 : 1,000	trace	0	–	–	<1	0	–	–
1 : 5,000	21	7	0	23	70	11	0	34
1 : 10,000	31	24	0	37	103	38	0	35
1 : 20,000	–	–	trace	56	–	–	<1	84
1 : 50,000	30	61	4	62	100	95	17	93

**Average of 3 colonies except in the check which is the average of 6.*

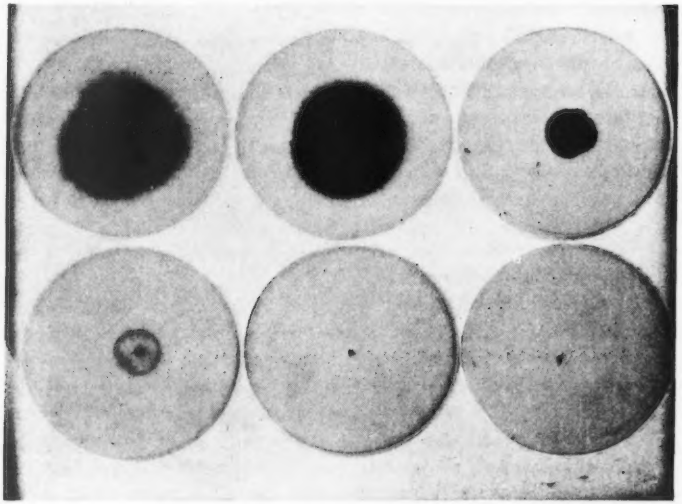

FIG. 1. *Reactions of Helminthosporium sativum (top row) and Ophiobolus graminis (bottom row) to different concentrations of mercuric chloride.*

Check *1 : 20,000* *1 : 5,000*

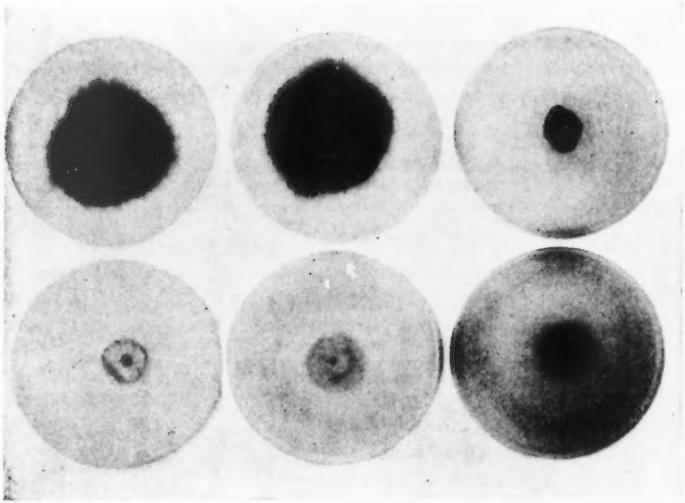

FIG. 2. *Reactions of Helminthosporium sativum (top row) and Ophiobolus graminis (bottom row) to different concentrations of silver nitrate.*

Check *1 : 10,000* *1 : 5,000*

sterilized with this chemical. Table IV also shows that *O. graminis* tolerates silver nitrate, at all concentrations tested, better than does *H. sativum*. This difference is especially marked at the concentration of 1 : 5,000, where the growth of *H. sativum* is only 11% of its check, whereas the growth of *O. graminis* is 70% of its check. These tests were repeated and gave almost identical results.

Acknowledgments

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References

1. Bateman, E. U.S.D.A. Tech. Bull. 346. 1933.
2. Broadfoot, W. C. Can. J. Research, 10 : 115-124. 1934.
3. Coons, G. H. and Strong, M. C. Mich. Acad. Sci. 9 : 65-88. 1928.
4. Coons, G. H. and Strong, M. C. Mich. State Coll. Tech. Bull. 115. 1931.
5. Hotchkiss, Margaret. J. Bact. 8 : 141-162. 1923.
6. Leonian, L. H. Am. J. Botany, 17 : 671-677. 1930.
7. Link, G. K. Botan. Gaz. 62 : 169-209. 1916.
8. Mead, H. W. Sci. Agr. 13 : 304-313. 1933.
9. Russell, R. C. Dom. of Can. Dept. Agr. Bull. 170. 1934.
10. Simmonds, P. M. Phytopathology, 20 : 911-913. 1930.

RECENT INVESTIGATIONS ON TOBACCO ROOT ROT IN CANADA[1]

By L. W. Koch[2]

Abstract

These investigations involved the direct microscopic examination of root systems of tobacco plants showing typical macroscopic evidence of infection by *Thielaviopsis basicola* (Berk.) Ferraris, supplemented by isolations from both diseased and healthy roots and infection experiments with the isolates obtained. Intensive microscopic examination of lesions on approximately 1600 roots affected with typical black root revealed the presence of many different organisms which were found to occur singly, in various combinations with one another and more especially in frequent association with *T. basicola.* In addition to *T. basicola* the organisms observed included the following: the so-called phycomycetous type of "mycorrhizal" fungus, representatives of the genus *Rhizoctonia,* including *R. Solani* as well as several endophytic forms of the type familiar in orchids, different members of the genus *Pythium,* and nematodes. In general, members of the Fungi Imperfecti appeared to be conspicuously absent. Microscopic evidence of parasitism on the part of each of the above-mentioned organisms was revealed by necrosis involving single cells, groups of cells or entire rootlets. The phycomycetous "mycorrhizal" fungus resembling in many respects the fungus reported as being almost universally present in the roots of strawberry, immediately upon penetration produces characteristic coils of mycelium in the outer cortical cells, ramifies deeper, and spreads producing first arbuscules and then vesicles in the deeper cortical tissues. Previous investigators (11, 15, 20, 24) have reported this or a closely related form of the fungus only in the roots of host plants. In the present paper it is reported for the first time completely invading the stems and leaves of moss plants, also the thallus of liverworts found growing in muck soil obtained from tobacco seedbeds. Daily microscopic examination of tobacco seedlings developing in muck known to contain the phycomycetous "mycorrhizal" fungus revealed the presence of the latter organism in 30% of the roots as early as five days after germination and in all of them 10 days after germination.

Isolation from 206 typically diseased roots has consistently yielded *T. basicola* as well as representatives of 21 genera of fungi, also bacteria and nematodes. The fungi isolated most frequently in association with *T. basicola* included representatives of the genera *Pythium, Rhizoctonia* and *Fusarium.* Preliminary infection experiments have demonstrated that one *Rhizoctonia* of the "*Solani*" type and three endophytes from the same genus, four forms of *Pythium* as well as *T. basicola* possess parasitic capability in the roots of tobacco, whereas two other forms of *Pythium,* three of *Rhizoctonia* and seven distinct members of the Fungi Imperfecti showed no capability of parasitism of the same host under identical conditions.

Introduction

In Quebec, where cigar leaf and pipe tobaccos are chiefly grown, black root rot of tobacco has for years been the most serious disease of this host. In Ontario the situation varies. In the older tobacco-growing districts of Essex and Kent counties where Burley and dark types of tobacco are grown chiefly, root rot is of major importance, while on the other hand, in the newer district such as Norfolk county where the more resistant flue-cured varieties are grown the disease is of relatively little importance. As a result of a tobacco disease survey initiated in 1933 by the St. Catharines laboratory, investiga-

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Contribution No. 432 from the Division of Botany, in co-operation with the Tobacco Division, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada.
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tions on both fundamental and control phases of the black root problem were begun in the following year. In the present article are embodied results of the fundamental investigations of the problem to date.

Review of Literature

Since Peglion (17) in 1897 in Europe, and Selby (22) in 1903 in America, reported *T. basicola* as the primary causal organism of black root of tobacco an extensive literature dealing with all phases of the problem has appeared. Since the general literature has been well reviewed by previous investigators no repetition will be made here. However, during the past decade information concerning more particularly host reaction and the habits of *T. basicola* both in the soil and on the host has increased rapidly and mention will be made of a few outstanding contributions along these lines. Conant (6) in 1927 showed a distinct correlation between resistance to invasion and cork formation in the tissues underlying the lesions. He found resistant varieties capable of effectually "corking out" the fungus at 20°, 25° and 30° C. In the susceptible strains, however, there was no cork formation at 20° C. but effective corking out at 30° C. Earlier investigators had shown that the amount of root rot in the field depended primarily upon the prevailing soil temperature. More recently the intensive investigations of Doran (8, 9), and Anderson and co-workers (1–3) have shown that *T. basicola* is also sensitive to soil acidity, pH values of 5.9 or higher being favorable for the growth of the fungus. Doran has also contributed much valuable information concerning the control of this disease by the use of acetic, pyroligneous and other acids (7, 10). Within recent years considerable progress has been made in various Tobacco Experiment Stations in the breeding of varieties resistant to root rot. Numerous varieties have been, and are now being produced combining necessary commercial qualities with resistance to *T. basicola*.

Method of Investigation and Materials Used

Investigations of root rot of tobacco in the past have been concerned entirely with *T. basicola*, the effect of the pathogen on the host having been studied in most instances by infection experiments in sterilized soils. In the present investigation direct microscopic examination of diseased roots growing under varying *natural* conditions both in the seedbed and in the field has been relied upon to give an accurate picture of black root of tobacco as it actually exists in nature. To supplement these studies, isolations were made from carefully selected material and, using pure cultures of the organisms obtained, infection experiments were conducted to test their pathogenicity.

Specimens of diseased plants were supplied as required, by the Dominion Experimental Stations at Farnham and L'Assomption in Quebec, and Harrow in Ontario. In addition, a supply of diseased material was always available from the seedbeds at the St. Catharines laboratory where seedlings were grown in virgin muck soil with *T. basicola* in pure culture added in some cases.

Microscopic Examination of Roots of Tobacco Affected with *T. Basicola* (Berk) Ferraris

In the microscopic studies, in addition to the materials mentioned above, tobacco seedlings grown in flats in the greenhouse were also examined daily *in toto* from the time of germination. Altogether, approximately 1600 roots of all ages were examined and with the exception of larger roots, where razor sections were made, the roots were prepared for examination by the method employed by Hildebrand (11) and Truscott (24) in their studies of the roots of strawberry. When the preparations were stained too deeply, entirely satisfactory results were obtained by de-staining slightly in clear lactophenol heated almost to boiling.

By this method it is possible to identify with accuracy in tobacco roots even different members of the same genus, particularly, for example, *Rhizoctonia* and *Pythium*. In relatively infrequent instances the occurrence of septate mycelium possessing no further diagnostic characteristic made identification impossible.

The organisms which were observed to occur singly, in asspciation with one another, or with *T. basicola* will be dealt with separately.

The Phycomycetous "Mycorrhizal" Fungus

An endophyte of the phycomycetous type of mycorrhizal fungus in many respects similar to the organism present in strawberry roots first described in detail in that host by O'Brien & McNaughton (19) and reported more recently by Hildebrand (11), Truscott (24) and Berkeley & Lauder-Thomson (4) was observed almost invariably in the roots of tobacco. It was associated in lesions with *T. basicola* more frequently than any other organism. During the course of his investigations on mycorrhiza, Peyronel (20, 21) in Italy included tobacco in his long list of plants in the roots of which he observed the phycomycetous "mycorrhizal" fungus. Since there appears to be no record of this fungus as it occurs in tobacco roots in America it is described below with a discussion of its relation to root rot of tobacco.

The characteristic, coarse, irregular and generally non-septate mycelium has been found to be particularly abundant in the unsterilized muck soil used for growing tobacco seedlings. This mycelium frequently gives rise to extremely fine lateral branches in which numerous septations have often been observed. Strands of the coarse mycelium may adhere closely to the epidermal cells of any portion of the root surface with the exception of the extreme tip, frequently spreading out over the surface at point of contact. After effecting penetration at a given point the fungus continues to grow externally in the direction of the long axis of the root, and again making contact with the root surface, forms another mycelial weft. This may be repeated many times, thus producing multiple infection. As a rule hyphae from these mycelial wefts penetrate the epidermal tissue intercellularly but sometimes directly through the cell wall. Immediately after entry the

mycelium gives rise to a distinct and characteristic coil within the epidermal cell. Similar coils are also often produced in adjacent and immediately underlying cells (Plate III, 4). In this respect the fungus differs from the organism of the same type found in strawberry. Hyphal strands ramify the underlying cortical tissue both inter- and intracellularly advancing more rapidly tangentially. Immediately after invasion of the cortical cells where coiling of the mycelium also occurs, though to a lesser extent than in the epidermal tissue, arbuscules appear (Plate I, 5, 6). The arbuscules which are similar in character to those produced by the fungus in strawberry roots appear to function as haustoria in their earlier stages and later are partially digested by the host cells. Subsequent to the formation of arbuscules, vesicles appear (Plate I, 1, 2, 4). For the most part the vesicles are intercellular though intracellular vesicles have also been observed. The vesicles of the organism in tobacco roots are typically sphaeroidal (Plate II, 1) and in this respect also differ from the fungus found in strawberry roots (11, 24). In numerous cases distortion of the root was observed as a result of the abundance of the vesicles. In other cases where mycelium alone was abundant, a constricted lesion resulted. Moreover the roots were always more brittle in the region of heaviest infestation and frequently broke at these points during manipulation.

Starch is absent in the cells of tobacco roots permeated with the fungus. In some cases no discoloration or death of cells has been observed in infected tissue. On the other hand necrosis involving single epidermal cells containing coils of mycelium, or groups of cells has been observed both in seedlings and in more mature plants heavily invaded by this fungus alone. The vesicles which are at first thin walled and the contents of which appear finely granular gradually develop a thicker wall and the contents become vacuolate. Occasionally vesicles have been observed which appear to be parasitized by a fungus of the *Rhizoctonia* type (Plate I, 1).

It is interesting to note that roots of tobacco plants from a certain field near Simcoe, Ontario where *T. basicola* appeared to be entirely absent were affected with brown root. Examination of these roots revealed a surprising abundance of the phycomycetous "mycorrhizal" fungus and an almost total absence of other fungi.

The same fungus was commonly observed growing in the muck of the St. Catharines seedbeds. Some of this muck soil was transferred to flats in the early fall and the latter were removed to the greenhouse, and tobacco seed was sown in them. A species of moss as well as a species of *Marchantia* common to muck soils partially overgrew the surface of these flats. Later, dying moss plants as well as a few diseased thalli of *Marchantia* were observed. Microscopic examination of these plants revealed the mycelium of the phycomycetous "mycorrhizal" fungus with an abundance of vesicles ramifying in both the stems (Plate III, 1) and leaves of the moss plants and the thalli of *Marchantia*, mycelium and vesicles extending to the growing tips of the plants (Plate I, 3). An examination of Plate I, 3 and Plate III, 1 will show that in

the moss plants the spherical vesicles characteristic of the organism in tobacco predominated.

In February, moss plants were obtained directly from the outdoor seedbeds and in certain of them the same mycorrhizal organism was also present.

These findings would indicate one means by which this organism can overwinter in tobacco seedbeds. It is believed that this is the first report of the presence of this phycomycetous "mycorrhizal" fungus in the aerial parts of plants.

To find out when tobacco seedlings may become infected by the phycomycetous "mycorrhizal" fungus, seeds of tobacco, variety Judy's Pride, were sown during the summer of 1934 in muck known to be heavily infested with the organism. Daily, from the time of germination ten seedlings were removed and examined microscopically. The results obtained appear in Table I.

TABLE I

RESULTS OF MICROSCOPIC OBSERVATION OF TOBACCO SEEDLINGS GROWING IN MUCK SOIL

Days after germination	Organisms present and percentage occurrence in roots				
	phycomycetous "mycorrhizal" fungus	*T. basicola*	*Rhizoctonia*	*Pythium*	Other fungi
5	30	—	—	—	—
6	80	10	10	10	—
7	90	30	—	10	—
8	100	60	20	20	10
10	90	20	10	10	10
13	100	40	30	30	30

It will be observed from an examination of Table I that five days after germination 30% of the seedlings were already infected by the phycomycetous "mycorrhizal" fungus and eight days after germination 100% had become infected. It is also interesting to note in this connection that six days after germination the seedlings showed primary infection by representatives of at least four different genera of fungi.

THE GENUS *Rhizoctonia*

Rhizoctonia Solani has been reported frequently in the past as the cause of damping-off of tobacco seedlings (5, 12–14, 18) and also in association with "sore shin" (13, 14), a characteristic root trouble of older tobacco plants in the field. *R. bataticola* has also recently been reported (25) causing the latter disease in Kentucky. During the present investigations representatives of the genus *Rhizoctonia* have been observed associated with *T. basicola* in the same lesions (Plate II, 3) especially in diseased plants from Quebec. However, *Rhizoctonia* has not been observed as frequently in diseased roots as the phycomycetous "mycorrhizal" fungus. Different forms of *Rhizoctonia* can be readily distinguished by microscopic examination. *R. Solani* is easily

recognized by the extremely coarse, septate mycelium with its characteristic branching and frequent anastomosis. On young seedlings the coarse hyphae effect penetration at or near the ground level and ramify in the cortical tissues of the root and stem causing the typical and well known symptoms of damping-off. In older plants which have not succumbed to typical damping-off, an abundance of superficial mycelium is often observed adhering to the root surface. Hyphae from this superficial mycelium penetrate cortical cells, producing in them pseudo-sclerotial complexes.

Infection of both seedlings and older roots by forms other than *R. Solani* is of much more frequent occurrence. In general, these forms give rise to sclerotia-like bodies which may occupy single cells or groups of cells in the cortical tissues and from which extends typical *Rhizoctonia* mycelium much smaller in diameter than that of *R. Solani*. These sclerotia-like bodies vary considerably, some consistently occupying only part of a cell whereas others completely fill the cell. Certain of them correspond closely to the monilioid bodies characteristic of the "orchid" type of *Rhizoctonia* (Plate II, 4) as described by Peyronel (21) and others. All degrees of infection by *Rhizoctonia* were observed both in close association with *T. basicola* and alone, and producing varying degrees of visible necrosis.

The Genus *Pythium*

Pythium has frequently been reported as a cause of damping-off of tobacco seedlings (5, 12, 14). As in the case of *Rhizoctonia*, *Pythium* was frequently observed during the present investigations in lesions on the younger roots of tobacco plants beyond the stage at which damping-off usually occurs. The representatives of this genus were observed alone (Plate II, 5, 6, 7), in combination with other organisms or in association with *T. basicola* (Plate II, 2). Microscopically the members of this genus in root tissues can be identified as such either by the presence of thin-walled conidia or zoosporangia, or as is more frequently the case, by the thick-walled oospores (Plate II, 5). Only in very early stages of infection is mycelium found in lesions. There is a wide variation in the type and size of spores observed, also a great difference in degree of necrosis, which suggests the presence of different members of the genus.

The Genus *Asterocystis*

Resting spores of *Asterocystis*, probably *Asterocystis radicis*, de Wild, were frequently observed in diseased roots of both seedlings and older plants in the field, particularly the latter (Plate III, 6 and 7). Peyronel in his investigation on mycorrhiza (20) observed *A. radicis* on both healthy and decayed roots of numerous plants and expressed the opinion that under conditions unfavorable to certain hosts the organism could become parasitic. Vanterpool (26) in 1930 concluded that only under exceptionally unfavorable conditions would *A. radicis* cause significant damage on cereals, and then only on oats. Truscott (24) in 1934 concluded this organism to be an important pathogen on strawberry roots under moist conditions.

In roots of tobacco this organism, which is readily identified under the microscope, was observed both alone and in combination with *T. basicola* or other organisms. In most tissues of tobacco roots where *Asterocystis* was observed, this fungus did not appear to cause much injury though in some cases where spores were particularly abundant, for example in plants grown in heavier soils, necrosis was frequently observed. It was concluded, therefore, that in ordinary soils under normal conditions little or no damage is caused by this organism but that in heavier soils, under conditions unfavorable to the host, this fungus may become a primary parasite or may be one of a complex of organisms causing a root rot.

Thielaviopsis basicola, (BERK.) FERRARIS

As was stated previously this organism has been recognized for many years as a virulent parasite on roots of tobacco and consequently no discussion of its parasitism will be made here. However, a point in connection with its morphology which apparently has not been pointed out by previous investigators may be mentioned here, namely, that though this fungus in common with many others possesses septate mycelium, its hyphae in the root cells are sufficiently characteristic to render diagnosis certain. The younger advancing hyphae have the appearance of a chain of crescent-shaped spores, the septa occurring at the constrictions in the chain. Penetration of cell walls is effected by thread-like hyphae which after penetration develop first a spear-like head followed by a chain of the normal, crescentic segments (Plate III, 5).

NEMATODES

The nematode *Heterodera marioni* (Cornu) Goodey has frequently been reported as causing galls on the roots of tobacco (23, 27), and *Anguillulina pratensis* (de Man) Goffart, has also been reported in association with a brown root of tobacco in alkaline soils (16). During the course of the present investigations, nematodes of a type distinctly different from *Heterodera*, were frequently observed alone or in black root lesions. When alone in the root tissues they are probably of no economic importance. Nevertheless, dead or dying cells or groups of cells were frequently observed surrounding single nematodes (Plate III, 2, 3). In such cases these dead cells might easily pave the way for certain facultative parasites which in the absence of infection courts would play no part in root rot. In all cases nematodes or their eggs were observed only in the cortical tissues of the roots.

Isolations from the Roots of Plants Affected with *T. Basicola*

In making isolations, individual diseased rootlets were first thoroughly washed under running water with a camel's hair brush and then transferred to Petri dishes containing potato dextrose agar (2½% dextrose), at the rate of five or six per plate. Apparently healthy rootlets from the same plants were treated in a similar manner. In some cases the medium was acidified, but in most instances non-acidified medium was used to permit the develop-

ment of Phycomycetes. As the fungi grew beyond the edge of the bacterial colonies single hyphal tips were cut off and removed to tubes. In nearly all instances more than one fungus was isolated from a diseased rootlet. Owing to the difference in growth rates of the various fungi it was sometimes possible to obtain all of them in pure culture while at other times this proved to be impossible. Frequently after the plantings were a week or more old, by which time the plate was usually overrun with numerous fungi, those which had developed more slowly produced spores near the diseased rootlet, by which they were identified. The results of isolations from 206 diseased rootlets and from 36 apparently healthy rootlets from the same plants are summarized in Table II.

TABLE II

ORGANISMS ISOLATED FROM LESIONS ON ROOTS OF TOBACCO SHOWING MACROSCOPIC EVIDENCE OF INFECTION BY *T. basicola* AND FROM APPARENTLY HEALTHY ROOTS OF THE SAME PLANTS

Organism	Number of isolates obtained		
	From Quebec materials	From Ontario materials	From apparently healthy roots
Thielaviopsis basicola	48 (2)*	17	3
Rhizoctonia spp.	36 (7)	13	3
Pythium spp.	18 (10)	28	1
Fusarium	31 (7)	11	17
Penicillium	6 (4)	3	1
Alternaria	4	1	3
Coniothyrium	6	2	Nil
Phoma	3	Nil	Nil
Pestalozzia	1	Nil	Nil
Hormodendrum	3	1	4
Cladosporium	2	Nil	Nil
Trichoderma	17	12	11
Mucor	11	7	4
Cephalosporium	2	Nil	Nil
Asterocystis	6	1	Nil
Nematodes	Fairly abundant	Sparse	Nil
Bacteria alone	3	Nil	1
Hainesia	3	Nil	Nil
Dematium	4	2	2
Verticillium	2	1	Nil
Yeast-like fungi	4 (4)	5	2
Rhizopus	6	5	7
Cephalothecium	2	Nil	Nil
Unidentified fungi	4	Nil	Nil

Numbers in brackets are the numbers of morphologically distinct strains isolated.

An examination of Table II shows that representatives from at least 21 genera of fungi as well as bacteria and nematodes were isolated from diseased rootlets selected because of macroscopic evidence of infection by *T. basicola*. It is true that *T. basicola* appeared most frequently in culture as would be expected, but isolates of *Rhizoctonia*, *Pythium* and *Fusarium* also occurred very consistently. *Rhizoctonia* was isolated most frequently from diseased specimens from Quebec, while *Pythium* appeared most frequently from the roots of plants from Ontario. It will also be observed that *Asterocystis*

appeared on seven occasions. The occurrence of this fungus in the plates was in the aggregate probably much more frequent than the tabulated results would indicate because during the earlier part of the work this organism, though present, was not identified. It is well known that *Asterocystis* is an obligate parasite and as such cannot be obtained in pure culture. However, in the instances mentioned above, the organisms appeared in abundance in the medium surrounding the diseased tissues as early as 24 hours after the tissue plantings were made and before other fungi had developed. It is possible that under favorable conditions of temperature and moisture, zoospores were produced by, and set free from, the resting spores within the root tissues, and these zoospores spreading over the surrounding medium gave rise to an abundance of mature spores of the fungus.

While fewer isolations were attempted from healthy roots it will be noted that there was almost complete overlapping from the standpoint of organisms isolated. However, this is to be expected when isolations are made from delicate tissues which cannot stand surface sterilization and which cannot be washed perfectly. In any case a low percentage of individual organisms was isolated from the apparently healthy roots, with the exception of *Fusarium*, *Trichoderma*, and possibly *Rhizopus*. To summarize the results of all isolations, the most noteworthy feature was the frequent appearance of both *Pythium* and *Rhizoctonia*. Their relative absence from the healthy rootlets would indicate that they, as well as *T. basicola*, are pathogens. It is already well known that both *Pythium de Baryanum* and *Rhizoctonia Solani* cause damping-off of tobacco seedlings, but none of the roots from which the isolations were made showed symptoms of damping-off and in most instances the plants used were beyond the stage when damping-off occurs. It will also be noted that seven morphologically distinct strains of *Rhizoctonia* were isolated. Only one of these was identical with *R. Solani* while four of the remaining six possessed characters as described by Peyronel (21) for the "orchid" type of *Rhizoctonia*. Similarly, ten morphologically distinct strains of *Pythium* appeared in the isolations. It may seem surprising that *T. basicola* did not appear more frequently but this is readily explainable when it is recalled that *T. basicola* is a relatively slow growing organism and as such cannot successfully compete with the numerous fast growing organisms that so frequently are associated with it in lesions on the host.

In view of the frequent appearance of *Fusarium*, *Trichoderma* and *Rhizopus* from apparently healthy roots, these organisms may be regarded as non-pathogenic.

Preliminary Infection Experiments

Preliminary infection experiments on tobacco involving 28 different fungi representing 11 genera as follows: *T. basicola* (2 strains), *Rhizoctonia* (6 strains), *Pythium* (7 strains), *Trichoderma*, *Alternaria*, *Fusarium* (6 strains), *Mucor*, *Cephalosporium*, *Verticillium*, *Coniothyrium* and *Pestalozzia* were conducted. Inoculum was prepared by growing each organism on sterilized crushed oats in 250 cc. Erlenmeyer flasks, the contents of each flask being

sufficient to inoculate three 5-inch pots containing steam sterilized soils. Check pots to which sterile oats were added in the same proportion were also prepared. Tobacco seed was sown in all pots and the roots of seedlings were examined microscopically for evidence of infection.

Certain of the organisms manifested primary parasitism (Fig. 1) which ranged from (a) invasion of host tissue without killing, *e.g.*, one strain of the "orchid" type of *Rhizoctonia* and one form of *Pythium*, through (b) local

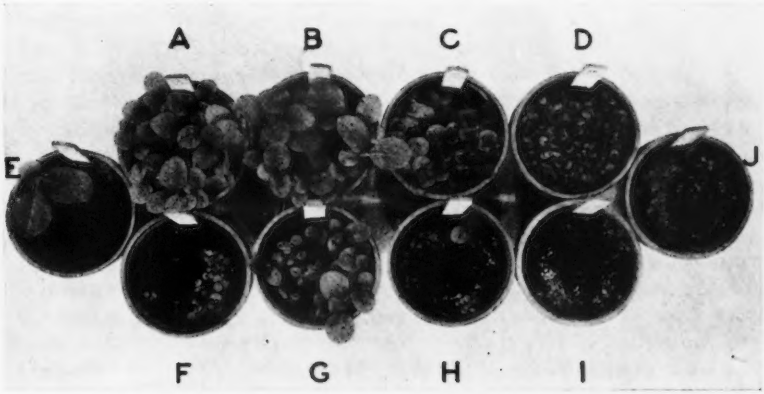

FIG. 1. *A, B, C and D—checks; E, F, G, H, I and J—inoculated. Soil in E and F each inoculated with a different strain of Pythium; A and B corresponding checks. Soil in G, H, I and J each inoculated with a different strain of Rhizoctonia; C and D corresponding checks.*

necrosis, *e.g.*, one strain of *Pythium*, to (c) general destruction of the complete root system, *e.g.*, *T. basicola* (2 strains); *Rhizoctonia* ("orchid" type, 2 strains) *R. Solani; Pythium* (3 strains). Negative results were obtained with all the other organisms mentioned above. Though all pathogenic strains of *Pythium* and two of the four strains of *Rhizoctonia* caused some measure of damping-off, all of them proved capable of causing definite root rot both in seedlings and in older plants.

It should be emphasized that the results of these infection experiments closely confirmed the evidence obtained (a) from microscopic examination of and (b) isolations from carefully selected roots showing evidence of black root.

Discussion

For many years *T. basicola* has been recognized as a virulent parasite on the roots of tobacco, and its pathogenicity has been repeatedly demonstrated by inoculation of plants in sterile soil. On hosts other than tobacco specific primary root parasites have also been demonstrated, *e.g.*, *Gibberella Saubinetii* (Mont.) Sacc., on corn and wheat, *Ophiobolus graminis* Sacc., on cereals *Phymatotrichum omnivorum* (Shear) Duggar, on cotton, as well as many others. On the other hand a somewhat different situation exists in the case

of certain other root rots, notable among which is strawberry root rot. In recent years the latter disease has received considerable attention. O'Brien and McNaughton (19) in Britain attributed the "Lanarkshire" root rot of strawberries to a phycomycetous mycorrhizal organism. Berkeley and Lauder-Thomson (4) in England demonstrated the pathogenicity of five members of the Fungi Imperfecti on roots of strawberries, and Truscott (24) in Canada proved by infection experiments on the same host the pathogenicity of members of seven widely separated genera of fungi, and obtained microscopic evidence of parasitism on the part of three additional obligate parasites of the phycomycetous type.

Black root rot of tobacco is more analogous to the first mentioned type of root rot, especially since a single virulent parasite is primarily responsible, and also because tobacco is an annual crop while strawberries are perennial. However, notwithstanding the fact that *T. basicola* is the primary causal agent of the disease which has come to be known as black root rot of tobacco, heretofore infection experiments involving *T. basicola* have been carried out using sterilized soil and therefore a true picture of black root rot as it actually exists in the field or in unsterilized seedbeds has not been presented. Of outstanding importance in the present investigations is the fact that numerous other organisms are indisputably associated with *T. basicola* in black root rot of tobacco. This conclusion was reached as a result of complete examinations of root systems (possible only by the use of a satisfactory staining and clearing technique) of seedlings and more mature plants growing in seed bed and field soils which produced typical black root rot. The results obtained from isolations and subsequent infection experiments supplemented and confirmed the evidence adduced from microscopic examinations.

Almost invariably other organisms, also capable of destruction of roots, were present either on the same lesions with *T. basicola* or on other rootlets of the same plant infected by this organism. Roots from the seedbed or field exhibiting macroscopic evidence of black root rot due to the presence of chlamydospores of *T. basicola* on the lesions reveal on close examination the presence of brown lesions also. Some of these are incipient infections by *T. basicola* on which chlamydospores have not yet developed, but many others are due to infections by one or more other organisms in various combinations.

Direct microscopic examination of a large number of roots of all ages has revealed the fact that a species of *Asterocystis* and an organism resembling the so-called mycorrhizal fungus reported as being almost invariably present in the roots of strawberry, possess parasitic capabilities on the roots of tobacco. Five morphologically distinct representatives of the genus *Pythium* and four isolates of *Rhizoctonia*, all of which were obtained from diseased roots showing infection by *T. basicola* have been proved by infection experiments to be each capable of primary parasitism on roots of tobacco. Several members of each of the above genera also caused damping-off, which phenomenon is in accordance with previous conceptions regarding members of these genera. In the present investigation, however, their importance was considered only in the

light of their capability of causing root rot. Numerous other organisms also isolated from roots infected with *T. basicola* proved in preliminary infection experiments to be non-pathogenic on tobacco. *T. basicola* as well as the other pathogenic organisms appeared in all possible combinations in both brown and black lesions. An evaluation of the importance of each of these organisms in root rot of tobacco is extremely difficult.

It is well known that during cool, wet seasons injury from *T. basicola* is most severe and in such a season it is also likely that *Pythium* would be abundant. In any case it would seem to be interesting that in a root rot disease considered heretofore to be caused strictly by one parasite, other organisms capable themselves of primary parasitism of the host should be so constantly associated with the chief causal organism, *T. basicola*, in this case. It is quite possible that investigations along similar lines of other root rot diseases analogous in this respect to black root rot of tobacco will yield similar results. From the standpoint of control the present results do not change the situation materially in respect to seedbeds because when seedbed soil is thoroughly sterilized all organisms are killed.

In the field, loss of plants is overcome by the use of resistant varieties. It is a well known fact that where a given crop is grown intensively within a given area, sooner or later epiphytotics develop. *T. basicola* has already in Quebec threatened to become a limiting factor in the growth of tobacco and the loss of plants, as previously stated, is only overcome by the use of plants resistant to *T. basicola*. There is no assurance, however, that these varieties which at present are resistant to *T. basicola* will also prove indefinitely resistant to certain of the other organisms which have been shown capable of primary parasitism, especially in view of the possibility of a constantly changing microbiological balance in the soil.

In concluding, it should be mentioned that the possibilities of investigating root rot of tobacco by the present method of attack are by no means exhausted. It is now planned to make daily microscopic examinations and comparisons of the complete root systems of seedlings and more mature tobacco plants growing under different environmental conditions to obtain as complete a picture as possible of the progress of infection by different organisms as it occurs in nature.

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References

1. Anderson, P. J. Soil reaction and black root rot of tobacco. (Abstract) Phytopathology, 18 : 131. 1928.
2. Anderson, P. J. and Morgan, M. F. Black root rot and soil reaction. Conn. Agr. Exp. Sta., Tobacco Sta. Bull. 6 : 59T-66T. 1926.

3. ANDERSON, P. J., OSMUN, A. V. and DORAN, W. L. Soil reaction and black root rot of tobacco. Mass. Agr. Exp. Sta. Bull. 229 : 117-136. 1926.

4. BERKELEY, G. H. and LAUDER-THOMSON, ISABEL. Root rots of strawberry in Britain. The "black lesion" type of strawberry root rot. J. Pomology Hort. Sci. 12 : 222-246. 1934.

5. CLINTON, G. P. and ANDERSON, P. J. Tobacco diseases observed in 1926. Conn. Agr. Exp. Sta., Tobacco Sta. Bull. 8 : 55T-57T. 1927.

6. CONANT, G. H. Histological studies of resistance in tobacco to *Thielavia basicola*. Am. J. Botany, 14 : 457-480. 1927.

7. DORAN, W. L. Acetic acid as a soil disinfectant. J. Agr. Research, 36 : 269-280. 1928.

8. DORAN, W. L. Effects of soil temperature and reaction on growth of tobacco infected and uninfected with black root rot. J. Agr. Research, 39 : 853-872. 1929.

9. DORAN, W. L. Increasing soil acidity as a means of controlling black root rot of tobacco. Mass. Agr. Exp. Sta. Bull. 276. 1931.

10. DORAN, W. L. Acetic acid and pyroligneous acid in comparison with formaldehyde as soil disinfectants. J. Agr. Research, 44 : 571-578. 1932.

11. HILDEBRAND, A. A. Recent observations on strawberry root rot in the Niagara Peninsula. Can. J. Research, 11 : 18-31. 1934.

12. HOPKINS, J. C. F. The care of tobacco seed beds. Rhodesia Agr. J. 34 : 7 : 736. 1927.

13. JOCHEMS, S. C. J. Rhizoctonia ziekten op Tabak in Deli Bull. Deli Proefstat. Medan-Sumatra 21, 13, 1926. (Abs. in Rev. Applied Mycol. 6 : 1 : 4, 1927, available only.)

14. JOHNSON, JAS. Tobacco diseases and their control. U.S. Dept. Agr. Bull. 1256. 1924.

15. JONES, F. R. A mycorrhizal fungus in the roots of legumes and some other plants. J. Agr. Research, 29 : 459-470. 1924.

16. LEHMAN, S. G. 54th annual report of the North Carolina Agr. Exp. Sta. for the fiscal year ending June 30, 1931. Progress report for year ending Dec. 1, 1931. 1932.

17. PEGLION, G. Marciume radicale delle piantine de tabacco causato della *Thielavia basicola* Zopf. Atti accad. Lincei, an. 294. S. 5. Rend. Cl. Sci. Fis., Vol. 6, semestre 2, fasc. 2, pp. 52-56. Roma, 1897.

18. PELTIER, G. L. Parasitic Rhizoctonias in America. Ill. Agr. Exp. Sta. Bull. 189. 1916.

19. O'BRIEN, D. G. and MCNAUGHTON, E. J. The endotrophic mycorrhiza of strawberries and its significance. West of Scotland Agr. Coll. Research Bull. 1 : 1-32. 1928.

20. PEYRONEL, B. Fructification de l'endophyte à arbuscules et à vésicules des mycorhizes endotrophes. Bull. Soc. Mycol. France, 39 : 119-126. 1923.

21. PEYRONEL, B. Prime ricerche sulle micorize endotrofiche e sulla microflora radicicola normale delle fanerogame. Rivista de Biologia, 4 : 463-485. 1923. 6 : 17-53. 1924.

22. SELBY, A. D. Tobacco diseases and tobacco breeding. Ohio Agr. Exp. Sta. Bull. 156. 1904.

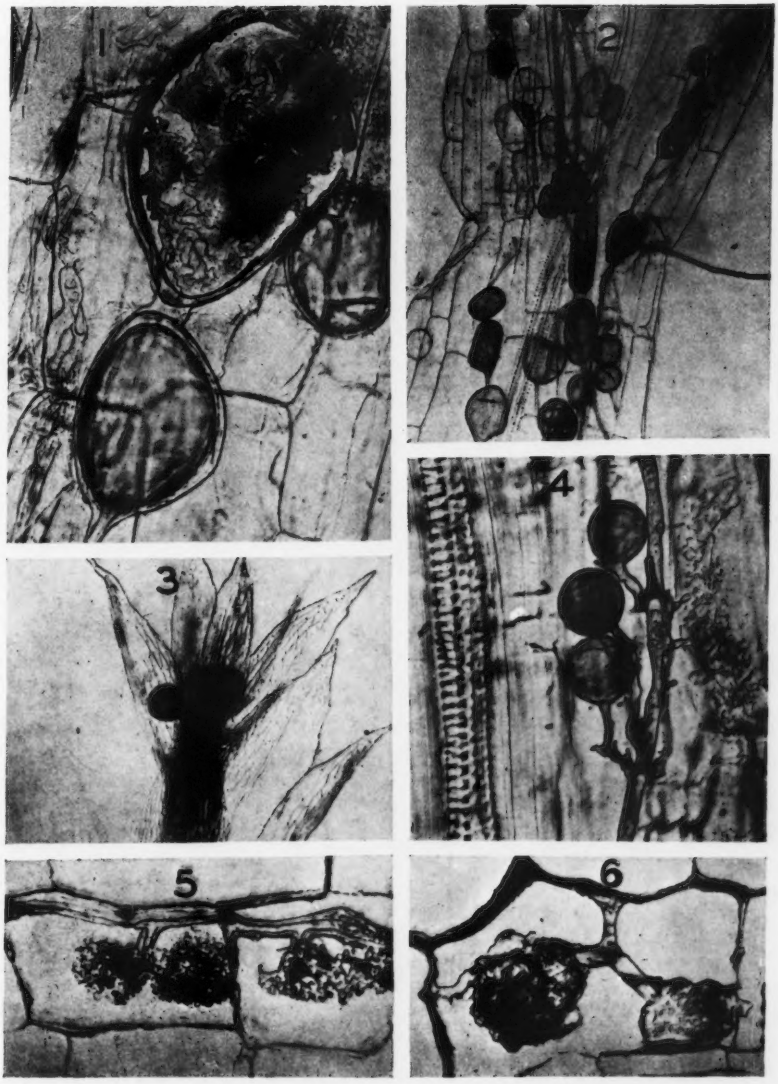
23. TISDALE, W. B. Tobacco diseases in Gadsden County in 1922 with suggestions for their prevention and control. Fla. Agr. Exp. Sta. Bull. 166. 1922.

24. TRUSCOTT, J. H. L. Fungous root rots of the strawberry. Can. J. Research, 11 : 1-17. 1934.

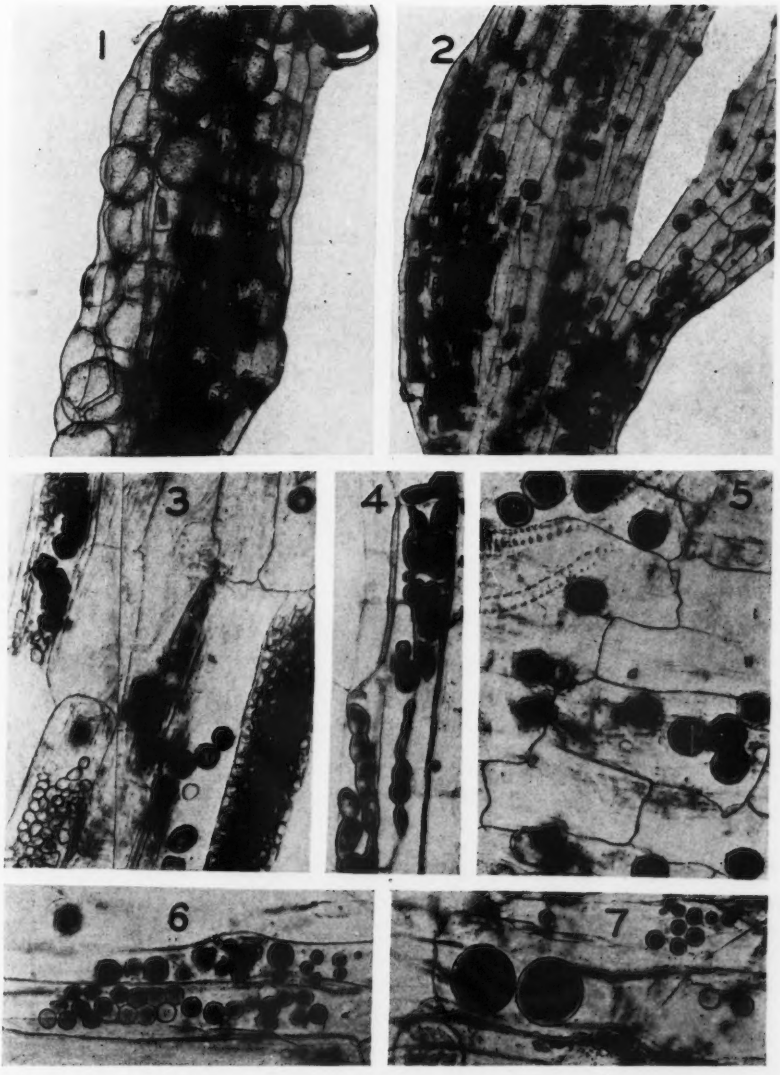
25. VALLEAU, W. D. *Rhizoctonia bataticola* causing sore shin of tobacco in Kentucky. Pl. Dis. Reporter 18 : 9 : 117. 1934.

26. VANTERPOOL, T. C. *Asterocystis radicis* in the roots of cereals in Saskatchewan. Phytopathology, 20 : 677-680. 1930.

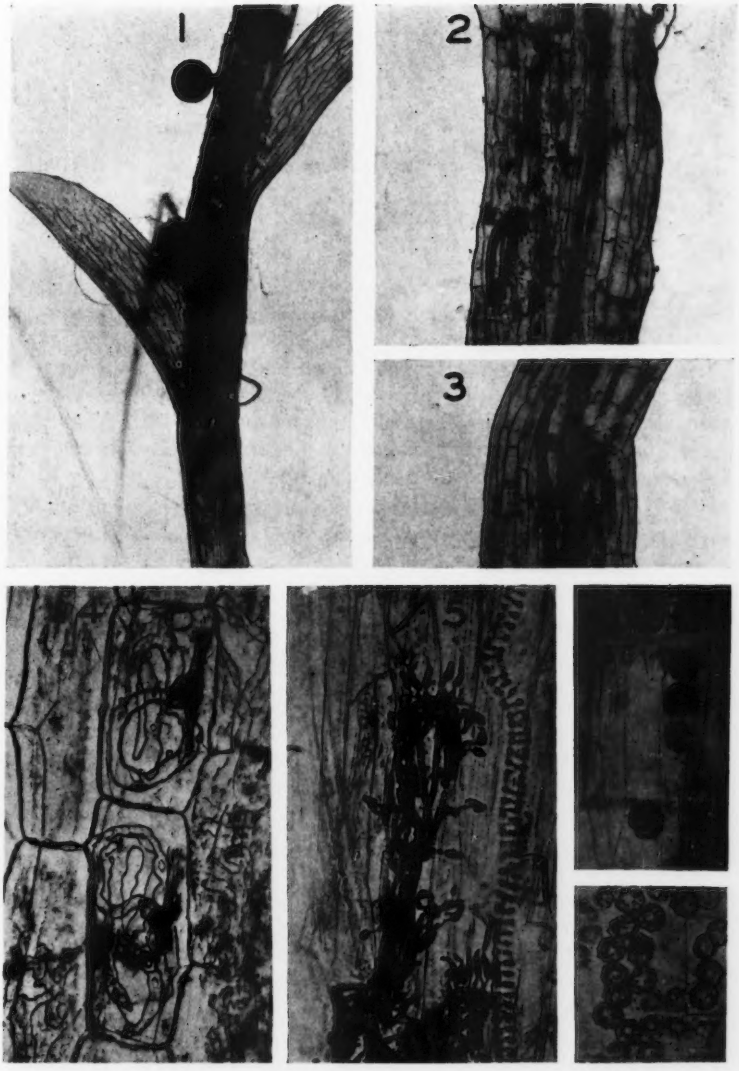
27. WOLF, F. A. and MOSS, E. G. Diseases of flue-cured tobacco with suggestions for application of palliative, preventive and remedial measures. N. Car. Dept. Agr. Bull. 263. 1919.



"Phycomycetous mycorrhizal fungus" (photomicrographs). All figures except 3, in roots of tobacco. FIG. 1. *Showing vesicles, the larger one of which contains Rhizoctonia-like mycelium, ×370.* FIG. 2. *Abundance of vesicles in root, ×80.* FIG. 3. *Vesicles at apex of moss plant, ×80.* FIG. 4. *Mycelium, from which both vesicles and arbuscules have arisen, ×340.* FIG. 5. *Arbuscules in early branching stage, ×340.* FIG. 6. *Later stage of 5 in "partially-digested" stage, ×340.*



Photomicrographs. FIGS. 1, 2 AND 3. *T. basicola associated with other organisms in black root lesions. Fig. 1, with "phycomycetous mycorrhiza", ×340; Fig. 2, with Pythium, ×110, Fig. 3, with Rhizoctonia, ×340. Fig. 4. "Orchid" type of Rhizoctonia, ×340.* FIGS. 5, 6 AND 7. *Spores belonging to different forms of Pythium present in roots, ×340; Fig. 5, produced by inoculation.*



Photomicrographs. FIG. 1. *Vesicles of "phycomycetous mycorrhiza" throughout stem of moss, ×80.* FIGS. 2 AND 3. *Nematodes and eggs in lesions on roots, ×80.* FIG. 4. *Showing characteristic coils of mycelium of "phycomycetous mycorrhiza" in epidermal cell, ×340.* FIG. 5. *Characteristic method of penetration of cortical cells by T. basicola, ×340.* FIGS. 6 AND 7. *Asterocystis; Fig 6, Spores in root tissue, ×340; Fig. 7, Spores on surface of medium, ×340.*

THE OCCURRENCE IN NATURE OF MUTUAL AVERSION BETWEEN MYCELIA OF HYMENOMYCETOUS FUNGI[1]

By Harold J. Brodie[2]

Abstract

A specimen of *Corticium calceum* Fr. discovered in the herbarium of the University of Toronto is clearly an example of the barrage phenomenon in nature. Two mycelia differing both in color and texture grew toward one another on the wood substratum and between them there developed a clearly defined gap or barrage. The gap is plainly not the work of insects and judging from several characters is a true barrage developed under natural conditions. Careful search among fungi which form flat expanses of mycelium (such as the Thelephoraceae) may show that the barrage effect occurs commonly in nature.

Mycelia grown side by side on nutrient agar frequently develop between them a line of demarcation. Some kind of mutual aversion exists which causes the hyphae of one individual to avoid the zone occupied by the other. This reaction may be manifest between mycelia belonging to different species and genera and in some instances between mycelia derived from spores of the same species. The aversion has generally been ascribed to the metabolism of one mycelium causing the liberation of certain chemical substances which are unfavorable to the development of the other mycelium concerned.

In recent times, much research has been devoted to the analysis of the pairing reactions of single-spore cultures of many kinds of fungi. Occasionally it has been reported that the aversion between individual mycelia is not a haphazard occurrence but that it depends upon inherited characters.

The first critical analysis of the cause of mutual aversion was made by Vandendries (1) in 1931, who demonstrated that in *Pleurotus columbinus* aversion is perfectly correlated with genetic constitution.

The following year, Dr. Vandendries and the present writer (3), working in collaboration, undertook a more detailed study of the problem of aversion. Monosporous cultures of the wood-destroying fungus *Lenzites betulina* proved to be ideal material. The aversion of certain mycelia for one another was striking, in some instances producing a gap between them nearly one centimetre in diameter (Plate I, Fig. 1). To this mutual aversion the name *barrage* was given.

It was shown that the pairing reactions of monosporous thalli are governed by two pairs of allelomorphic factors, one of which (the *B* factor) is responsible for aversion. The aversion is entirely dependent upon the genetic constitution of the mycelia which are confronted with one another.

Vandendries and Brodie concluded that it is difficult to explain the results of their experiments by the assumption that the repulsive effect is of a chemical nature. The barrage seemed capable of manifesting itself between mycelia

[1] *Manuscript received May 28, 1935.*
Contribution from the Department of Botany, University of Toronto, Toronto, Canada.
[2] *Fellow of the National Research Council (United States of America) at the University of Toronto.*

which were separated by a thin glass partition, and the degree of manifestation appeared to be dependent upon the nature and thickness of the partition. Further investigations by Vandendries (2) and independent researches by Brodie (unpublished) in part confirm the preliminary work and in part contradict it.

The details of this experimental work will be recorded elsewhere. The purpose of this communication is to report the finding of the barrage effect in nature.

It had already been shown that in *Lenzites betulina* aversion can be developed between any two mycelia which differ in the *B* factor. If this condition is fulfilled, a monocaryophyte may repel either another monocaryophyte or a dicaryophyte, and two dicaryophytes may repel one another. In the Hymenomycetes, mycelia occurring in nature are usually dicaryophytic. Since in *L. betulina* dicaryophytes may repel one another, it appeared not unlikely that examples of the barrage effect might be found among specimens growing under natural conditions.

Professor H. S. Jackson, in discussing this point with the writer, mentioned that there was a specimen in the herbarium of the University of Toronto which resembled the barrages obtained on culture plates. The specimen had been noticed by Dr. R. F. Cain and had been discussed by him and Professor Jackson. Being unaware of the possibility of a barrage being formed between dicaryophytic mycelia, Professor Jackson had not considered the specimen of importance until discussing it with the writer.

The specimen (No. 6772 in the Herbarium of the University of Toronto) belongs to the thelephoraceous species *Corticium calceum* Fr. It is growing on a piece of rotted pine wood and was collected by Professor Jackson on Bear Island in Lake Timagami, Ontario, July 30, 1934. The yellowish fructification is thin and appressed, having a somewhat chalky appearance. Two mycelia, differing both in color and texture, have grown toward one another on the wood substratum. Between them is a clearly defined narrow gap (Plate I, Fig. 2) extending the entire length of the specimen (15 cm.). When examined under the microscope, the gap is found to be almost entirely devoid of hyphae (Plate I, Fig. 3). It has also many characters typical of the barrages seen in culture and there is every probability that it is a true barrage developed under natural conditions.

The facts which make such an assumption seem reasonable are as follows:

(*i*) The mycelium on one side of the barrage differs in color and texture from the mycelium on the other side. One mycelium is dark ivory in color, rough, and finely cracked; the other is pale ivory to whitish, smoother, and less cracked. Microscopic examination of sections taken from both sides of the barrage line shows that both mycelia belong to the same species. The difference between the thalli may be accounted for by assuming that one is older than the other. One mycelium had become established on the log. Another inoculation of the same fungus then occurred and the younger

PLATE I

FIG. 1. *Barrage developed between two haploid mycelia of Lenzites betulina, mycelium No. 29 (AB) on the upper side of the barrage and No. 3 (Ab) on the lower side.* ×⅔.

FIG. 2. *Barrage developed in nature between two diploid mycelia of Corticium calceum Fr.* ×½.

FIG. 3. *Enlarged portion of the specimen of Corticium calceum shown in Fig. 2.; a, mycelium accumulated on one side of the barrage forming a "drift".* ×4.

mycelium grew toward the older until checked by the barrage action. On the other hand, the two mycelia may possibly have resulted from simultaneous inoculations and the differences in color and texture may be merely the differences between individuals. This seems less likely than the first hypothesis, as the differences are exactly those ordinarily noted between young and old mycelia of fungi belonging to the Thelephoraceae.

(*ii*) At certain points along the barrage line (Plate I, Fig. 3, *a*), mycelium from one side has accumulated to form a kind of drift such as is frequently seen on old culture plates where the vegetation accumulates and does not grow beyond an area delimited by the barrage action.

The two characters described discount the possibility of the gap between the mycelia being due to the ravages of a bark beetle or some other insect. Also there is a complete lack either of mycelial fragments or of excrement.

The specimen had been fumigated before inclusion in the herbarium and there was consequently no possibility of obtaining a culture of the fungus.

As far as the writer is aware, this is the first time that a barrage has been observed in nature. There is no reason why mycelia should not repel one another under natural conditions as they do under the conditions of artificial culture. Barrages to be noticeable would have to be developed under conditions favoring the development of a flat expanse of mycelium. Many of the fungi belonging to the Thelephoraceae form flat thalli, and it may well be that careful search among specimens belonging to this group of fungi will show that the barrage effect is a relatively common occurrence in nature. In the autumn, after the leaves have fallen, one frequently finds sheets of mycelium close to the ground under the moist leaves. It would not be surprising to find that barrages are developed between contiguous mycelial mats. They should be looked for with a view to determining whether or not the barrage effect as described by Vandendries and Brodie is a widespread or only a rare phenomenon.

The observation of the true barrage effect in a fungus under natural conditions is also of importance in being a possible indication of the heterothallism and tetrapolarity of that fungus.

Acknowledgments

It is a pleasure for the writer to acknowledge his gratitude to Professor H. S. Jackson and Dr. R. F. Cain of the Department of Botany of the University of Toronto for calling his attention to the specimen as well as to Dr. J. W. Groves for assistance in taking one of the photographs reproduced (Plate I, Fig. 3) in this article.

References

1. VANDENDRIES, RENÉ. La tétrapolarité sexuelle de *Pleurotus columbinus*. La Cellule, 41 : 267-277. 1932.
2. VANDENDRIES, RENÉ. Nouvelles recherches expérimentales sur les barrages sexuels de *Lenzites betulina* (L.) Fr. Genetica, 16 : 389-400. 1934.
3. VANDENDRIES, RENÉ and BRODIE, HAROLD J. Nouvelles investigations dans le domaine de la sexualité des Basidiomycètes et étude expérimentale des barrages sexuels. La Cellule, 42 : 165-209. 1933.

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LIGHT AS A CONTROLLING FACTOR IN THE GROWTH OF *BALANUS BALANOIDES*[1]

BY A. BROOKER KLUGH[2]* AND CURTIS L. NEWCOMBE[3]

Abstract

Areas on different sides of the wharf of the Atlantic Biological Station that had been denuded in the spring and that had different degrees of illumination were selected and the growth of *Balanus* followed throughout the summer season. The results show (i) that there is a significant correspondence between rate of growth of *Balanus* and the amount of illumination, (ii) that the difference between the amount of growth at widely separated vertical levels is quite similar to the difference in the increment of growth in areas on the same level which are subject to wide variations in the amount of illumination, and (iii) that during the summer of 1931, there was no appreciable set of barnacles after June 6 in the St. Andrews region. The presence of a large number of elongated barnacles may result from the operation of one main factor or from the combination of several. It may indicate (i) that there has been a very heavy set, in which case exceptionally favorable growing conditions cannot necessarily be inferred, or (ii) a rapid rate of growth even though the set has not been particularly thick, or (iii) the presence of favorable growing conditions together with a good set. Each of these possibilities should be considered in the evaluation of *Balanus balanoides* as an organic indicator.

Introduction

During the course of ecological work on intertidal animals, it was observed that barnacles, *Balanus balanoides*, growing on the wharf at the Atlantic Biological Station, St. Andrews, New Brunswick, showed size variations in areas exposed to different light conditions.

Observations made during the summers of 1929 and 1930 suggested the probable importance of light as a controlling factor of growth and resulted in the formulation of our hypothesis, namely, that light intensity plays a far greater role in the growth of the invertebrate fauna of the intertidal belt than has heretofore been realized. Measurements were made on August 22, 1929, of a *Balanus* community growing on the under side of a ledge of sandstone conglomerate occupying a position in the intertidal belt near the mean low water level. The barnacles were packed closely together and their average length and width were practically the same, namely, 18 mm. In no other part of the intertidal zone were specimens found that had attained these dimensions. This, we believe, was due to the fact that growth is favored

[1] *Manuscript received June 10, 1935.*
Contribution from the Zoological Laboratories of Queen's University and the University of Toronto.

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[3] *Formerly Assistant in Invertebrate Zoology, The Johns Hopkins University; now Instructor in Zoology, University of Maryland, College Park, Md., U.S.A.*
**The sudden death of Professor Klugh has made it necessary for the final revision of this paper to be made by the junior author.*

not only by the low level but also by total protection from direct sunlight (2). Again, on a movable beam which supports the float on the south side of the wharf, barnacles of the same set were found to be about twice as large on the "north" side of the beam (*i.e.*, on the inside surface very near the wharf) as on the exposed "south" side. Consequently, during the summer of 1931, areas A_1, A_2 and A_3, on the outside of the wharf at the same tidal level but with different degrees of illumination, were studied and also areas at different tidal levels for comparisons with the above. (Fig. 1).

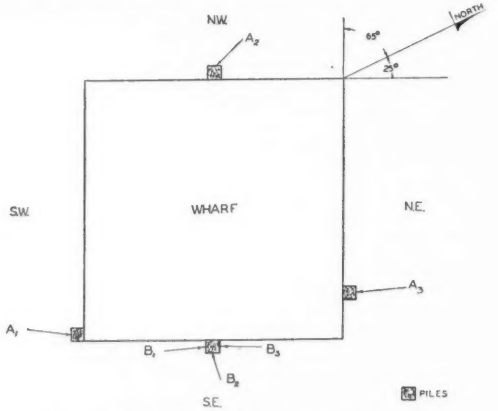

FIG. 1. *Diagram showing the approximate position of the several quadrats selected for study on the wharf at the Atlantic Biological Station, St. Andrews, New Brunswick.*

On the three exposed sides (B_1, B_2 and B_3) of a vertical wharf pile, 18 cm. in cross section extending out from the centre of the "east" side of the wharf, areas which were covered with barnacles of this year's growth were selected for intensive study. The position of the wharf is such that the side hereafter termed the west side (A_2) faces 65° west of north—true bearing—(Fig. 1). The quadrats A_1, A_2, A_3, and B_1, B_2, B_3 are listed in decreasing order of magnitude with respect to the total amount of illumination.

Methods

The light measurements were made with a Bell and Howell photometer, Model B, an instrument designed for photographic purposes. The principle of this instrument is that the image of the filament of a small bulb is matched in intensity against an object which is viewed through the photometer, the image being superimposed upon the object. The current is supplied by a flashlight battery in the handle of the instrument and is controlled by a rheostat, the turning of which is indicated on a scale on the barrel. For details concerning this instrument including its efficiency and methods of use for ecological purposes, the reader is referred to a paper by the senior author (1). The manner in which the instrument was used in the present

investigation was to place a neutral gray card in front of, and parallel to, the quadrats, and to reduce the readings made, with this card as a standard surface, to percentages of the highest intensity recorded.

Counts and measurements of barnacles were made on June 6 and 13, July 14, Aug. 4–6, and Sept. 8. Records of abundance were obtained by counting the barnacles on several centimetre and decimetre square areas chosen at random, and then computing the arithmetic averages. The maximum height and width were recorded and counts were made of the numbers in each size group. On a basis of these results, it has been possible to determine the variation in amount of growth on the different sides of the wharf and also the increments of growth during certain periods throughout the season.

An expression of the variation in growth and numbers of barnacles in the quadrats studied does not lend itself readily to statistical treatment. This will be apparent to the reader in view of the widely felt lack of satisfactory quantitative methods for community study (3). Therefore, it has been considered impractical to attempt an accurate mathematical representation of the increments of growth. This, however, does not prevent a fairly accurate estimate based on numerous observations of the selected quadrats and on considerable cruising in the barnacle communities of the adjacent intertidal area. The fact that there are such significant differences in the growth increments at the various stations minimizes the need for a more refined treatment.

Results

Our observations clearly demonstrate a correspondence between barnacle growth and amount of illumination. In view of the fact that all the stations were within 14 metres of each other, it is reasonable to assume that other determining factors are quite similar. From previous observations it had been noted that the dog whelk *Purpura lapillus* preyed upon *Balanus balanoides*, hence in order to insure that these predators would not invade the habitats under observation, screens of wire netting were erected to exclude them.

Measurements and counts made near quadrats A_1, A_2 and A_3 definitely indicate an increase in the rate of growth of the different classes accompanying a decrease in amount of illumination.

On June 6, 1931, an examination was made of barnacles, two years old, growing on areas immediately adjacent to each of the three quadrats. They were found to be comparatively uniform in size and distribution. Those adjacent to A_1 were approximately 5 mm. in height and 6 mm. in width; those adjacent to A_2, 7 mm. in height and width; and those near A_3, 15 mm. in height and 9 mm. in width.

The stations that were denuded on October 30, 1930, were observed on February 31, 1931, and a practical absence of plants and animals was noted. The next records were made during the second week in June when, on the basis of the different sizes of barnacles present, it was concluded that there had been, up to that time, at least two distinct sets at intervals of about two weeks. To determine the extent of any subsequent set that might take place, an area 9.5 cm. by 15 cm., near quadrat A_1, was denuded together with an area 19 cm. by 20 cm., adjacent to quadrat A_3.

Examination of these areas on July 14, 1931, gave the results shown in Table I.

TABLE I

Date	Quadrat	Number	Species	Height	Width
July 14, 1931	Near A_1	3	*B. balanoides*	1–1.5 mm.	1–1.5 mm.
		7	*B. balanoides*	< 1 mm.	< 1 mm.
	Near A_3	13	*B. balanoides*	1–1.5 mm.	1–1.5 mm.

It appears, therefore, that during this season the set of barnacles after June 6 was of minor importance.

Light Data

It is obvious that the data on the light factor most desirable for the purpose of this investigation would be the total amount of light received by each quadrat during the course of the investigation. It is equally apparent that such data are extremely difficult to obtain because of the large number of variables involved; the weather conditions varying from day to day and from hour to hour, the intensity of the sunlight decreasing from June to September (the period covered by these observations), and the tidal amplitude varying from day to day so that the quantity and the quality of the light reaching a quadrat while under water varies from day to day. The data which are of significance in giving a picture of the light conditions in this region are as follows: The pyrheliometer value of full noon sunlight at this station varies from 1.55 gm. cal./cm.^{2}/min. in September. The sunlight first strikes the "south" side of the wharf (A_1) at 8 o'clock (sun time) and leaves it at 8 p.m., or at sunset. It is on the "west" side (A_2) from 2 p.m. until sunset while it is only in June and early July that the early morning sun is on the "north" side (A_3) for about an hour. Of the quadrats on the vertical pile beneath the plank walk of the wharf the only one which receives any appreciable amount of sunlight is B_1 and it is exposed to the sunlight during only a short period in the morning. The light values of the quadrats for different weather conditions and times of day, as read on the Bell and Howell photometer and expressed as percentages of the highest value obtained, are shown in Table II.

TABLE II

——		A_1	A_2	A_3	B_1	B_2	B_3
Bright sun	9:30 a.m.	5	5	13	2	4	2
Bright sun	2:00 p.m.	100	90	7	17	8	3
Cloudy-bright	4:00 p.m.	25	50	12	13	7	8
Foggy	9:00 a.m.	13	17	30	2	4	2

The significant point of difference with respect to the light conditions in the respective quadrats—A_1, A_2, A_3 and B_1, B_2, B_3, lies not so much in the variations in actual intensity during one particular time of day as in the variations

in total amount of illumination resulting from differences in the length of the period of exposure to sunlight.

Barnacle Data

During the second week in June, measurements and counts were made at quadrats A_1, A_2, and A_3, the data obtained being shown in Table III.

TABLE III

Date, 1931	Quadrat	No. of specimens per dm.^{2}	Height, mm.	Width, mm.
June 13	A_1	300	2–4	2–4
		2060	<1 mm.	<1 mm.
June 6	A_2	1100	4–5	4–5
		2000	1–2	1–2
June 13	A_3	1200	5–8	4–6
		800	1–5	1–3
Aug. 4	A_1	220	4–7	4–7
		210	3–4	3–4
		270	2–3	2–3
		370	1–2	1–2
		250	<1 mm.	<1 mm.
Aug. 6	A_2	600	7–8	4–5
		200	3–4	2–3
		100	2–3	1–2
Aug. 4	A_3	600	8–13	4–7
		700	5–6	2–3

From Table III, it is evident that there are significant differences in the amount of growth and in the numbers of individuals within the size groups. Also, it is clear that the amount of growth is in inverse proportion to the amount of illumination incident upon the habitats. On the basis of the data collected in August, 1931, Fig. 2 has been constructed. For comparative purposes, the approximate volume has been calculated by multiplying the maximum width squared, by the height and by the number of specimens. Comparing the two sets of data presented above and considering in each case the numbers of the largest and smallest classes, it is seen that there are far greater numbers of large barnacles in quadrat A_3, less in quadrat A_2 and still less in quadrat A_1, and that the reverse is true in the case of the small barnacles. We consider this to be due chiefly to two factors:

(i) Increase in amount of growth which, as is particularly evident in the case of those less than 1 mm. in height, results in a marked reduction in the numbers of this class at quadrats A_2 and A_3.

(ii) The lethal effect produced by the mechanical action of crowding under conditions favorable for growth accounts for an almost total absence of barnacles less than 1 mm. in height in quadrats A_2 and A_3 (2).

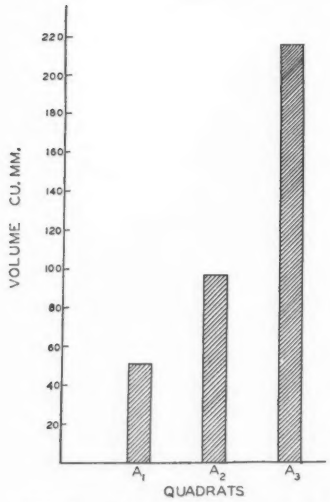

FIG. 2. *Effect of variations in the amount of illumination between quadrats A_1, A_2 and A_3 on the growth of Balanus balanoides. Width² × height × number of specimens is approximately equivalent to the volume which is expressed in thousands of cubic millimetres per decimeter square.*

The efficacy of the last-mentioned factor in accounting for reduction in numbers of small barnacles is suggested from observations at quadrat B_3 where there have been observed numerous dead specimens less than 2 mm. in height.

The difference in the amount of growth in quadrats A_1 and A_2 is probably less than that in quadrats A_2 and A_3, while the difference in the amount of growth in quadrats A_1 and A_3 is very definite.

The amount of growth in quadrats B_1, B_2 and B_3 already described is also proportional to the difference in the amount of illumination, thus being in agreement with results obtained from quadrats A_1, A_2, and A_3.

It is not unusual to find areas in which the barnacles are crowded and unusually long. A not uncommon interpretation of this phenomenon is that the crowded condition is a result of thickness of set. It was observed that the set on the different sides of the wharf was approximately equal. In quadrat B_1 and also quadrat A_1, there was no evidence of crowding on August 4. Some crowding was noted at quadrat B_2 and considerably more at B_3. In the light of these findings it appears that increased elongation may be interpreted as due to crowding which, in turn, is due to favorable growing conditions and not necessarily to an unusually thick set (See 4 and 5).

Acknowledgments

The authors take pleasure in acknowledging the aid received in the form of facilities from the Biological Board of Canada and in the form of instruments from the National Research Council of Canada.

References

1. KLUGH, A. BROOKER. An ultraviolet photometer for field use. Ecology, 11 : 518-522. 1930.
2. NEWCOMBE, CURTIS L. A study of the community relationships of the sea mussel, *Mytilus edulis* L. Ecology, 16 : 234-243. 1935.
3. NEWCOMBE, CURTIS L. Certain environmental factors of a sand beach in the St. Andrews region, N.B., with a preliminary designation of the intertidal communities. J. Ecology, 23 : 334-355. 1935.
4. RICE, LUCILE. Peculiarities in the distribution of barnacles in communities and their probable causes. Pub. Puget Sound Biol. Sta. 7 : 249-258. 1930.
5. SHELFORD, VICTOR E. Laboratory and field ecology. Williams and Wilkins Co., Baltimore. 1929.

THE MOLLUSCAN FAUNA OF MEACH LAKE, QUEBEC[1]

By A. La Rocque[2]

Abstract

The shallow water zone (0–10 ft.) of Meach Lake provides three types of bottom:— rock, sand and mud. Certain species of mollusca live in all three habitats, some in two and some in one. Seventeen species were found, two of which were confined to the drainage. Nine of the seventeen are recorded for Meach Lake for the first time. The number of species and the size of individuals are both smaller in the inlet and in the streams flowing into the lake than in the lake itself. A dwarfed fauna occurs at the outlet. One species has apparently disappeared from the lake in a period of two years.

Introduction

The Gatineau valley is the favorite resort of thousands of tourists and fishermen to whom its lakes are a major attraction. Without the lakes the region would lose its appeal; hence it is most important to learn as much as possible of the complicated associations of life forms which help to maintain conditions as they are in these lakes. The role of the mollusca in the maintenance of this equilibrium is one of major importance, a fact appreciated by all biologists who have to deal with lake life. This paper deals in detail with the mollusca of one lake, their ecology and distribution. When more data of a similar nature are available for other lakes it will be possible to estimate the relative value of the mollusca in them as fish food, purifying agents, scavengers, etc., thus providing a better understanding of the means of preserving our lakes in their present state.

This paper embodies the results of observations made on various week-end trips to Meach Lake, and one week devoted to collecting material for the National Museum of Canada in September, 1934.

Meach Lake was chosen as one of four lakes of different types in eastern Canada whose molluscan fauna is to be compared in an exhibit in the National Museum. This exhibit will show the differences brought about by various environmental conditions and attempt an explanation of their causes; the other lakes chosen are MacKay Lake, near Ottawa, White Lake in Renfrew County and Lake Erie.

The peculiar character of the mollusca of Meach Lake has long been known to Ottawa conchologists. As long ago as 1880, Heron (3) recorded a peculiar *Physa* which he identified as *Physa lordi* Baird and which was later distinguished from it by Baker under the name *latchfordi*. Latchford and Poirier (12, p. 132) called attention to the large size of the *Helisoma anceps* found there. Since then the lake has been visited many times by conchologists, and their published results are discussed in a section of this paper.

[1] *Manuscript received May 30, 1935.*
Contribution from the Bureau of Economic Geology, Department of Mines, Ottawa, Canada. Published by permission of the Director.
[2] *Museum Assistant, Division of Palaeontology, Geological Survey.*

The writer visited Meach Lake on three occasions: June, 1932, August, 1933, and September, 1934. These visits produced many specimens of species already recorded and ten species not previously recorded for the lake. All the material collected was deposited in the National Museum of Canada.

Methods

The primary object of the work being to obtain specimens for the Museum, very little time could be spent on the examination of the deeper parts of the lake. It was known from earlier visits that the lake could be divided into three habitats, more or less grading into each other and an exact knowledge of the relative proportions of these habitats was obtained by rowing slowly

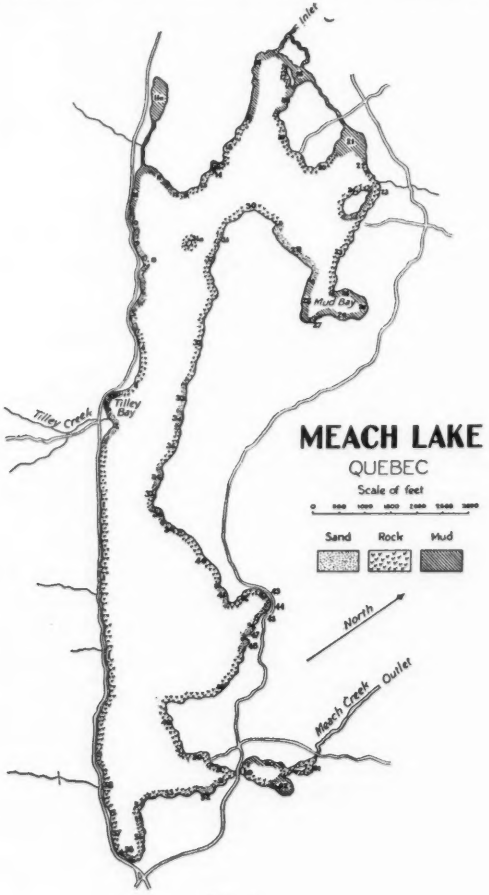

FIG. 1.

around the lake, stopping wherever a change occurred to collect specimens. The character of the bottom and the species present were then carefully recorded, the extent of the station being indicated on the map. Collections from each station were kept separate so that the specimens from each could be compared later. After a while it became evident that the same species could be found on a given type of bottom and specimens were noted only, not collected.

No deep water dredging was done, but species could be recognized in water as deep as ten feet, the water of the lake being reasonably clear. Since it has been the experience of most collectors to find mollusca most abundant within the ten-foot contour, it is probable that dredging would not materially increase the number of species found except perhaps for *Pisidium* and *Valvata*.

All collecting was done by hand, and the majority of specimens collected were alive. A hand sieve and rake* were also used, the former being very useful in obtaining *Sphaeriidae* and the latter for *Campeloma*.

As the writer has not seen the rake method described in the literature, and can vouch for its effectiveness, a brief description of it may be useful: Use an ordinary garden rake with a long handle. Rake the sand over a given area, say 4 × 4 ft., lightly or deeply according to the species sought. Wait until the sand settles again and the water clears. The specimens dislodged by the rake are now in plain sight and can be picked up by hand. This method produced *Campeloma* by the dozen where only a few specimens had been obtained by hand or with the hand sieve. The tell-tale mound which indicates the presence of the species on a clay bottom was not observed but dead shells along the shore and on the sand indicated the presence of the species in the vicinity.

Physiography

The correct interpretation of the peculiar fauna of Meach Lake must rest on an understanding of its situation. The lake is the fourth in order of the four major lakes of the Meach Creek drainage which are: Taylor, Philip, Harrington and Meach. Most of its water comes from Harrington Lake, through a winding, shallow inlet, and a small amount is also derived from the half-dozen creeks which drain into it. The outlet is through McGoey lake into Meach Creek, thence into the Gatineau River.

The lake is long and narrow, with a few shallow bays. Where the shore is rocky the hills descend abruptly into the lake, the water deepening quickly.

The northwest wind, which is not uncommon, has a tremendous sweep along the entire length of the lake and raises fair-sized waves which dash against the rocky shores. The exposed portions are accordingly unfavorable to mollusca, and at the southeast end, where the cliffs are almost vertical, none are found.

* *The rake method was shown to the writer by Mr. C. H. Young of the Museum staff, who has used it to advantage in collecting both marine and fresh-water shells from sand.*

The outlet of the lake has been dammed so that the water level is fairly constant. Aside from this dam, human influence on the lake is slight. Along the southwest shore, especially near the east end, quantities of boulders were dumped into the lake to widen the road-bed, changing a sand-clay habitat to rock. Sewage dumped into the lake is negligible. A sawmill which ceased operations many years ago may have caused an accumulation of sawdust in the past but no sign of it is to be found at present.

Previous Work

The first record of shells from Meach Lake is by Heron (3) 1880. Four species are enumerated: *Unio complanatus* (Dillwyn), *Planorbis bicarinatus* Say, *Limnaea stagnalis* Linn. and *Physa lordi* Baird.

The next paper is by Latchford (6), 1882. It mentions three species from Meach Creek, one from McGoey Lake and two from Meach Lake, only one of which, *Anodonta marginata* Say, had not been recorded by Heron.

Two species were added to the list by Small and Symes (15), 1882: *Limnaea megasoma* Say and *Limnaea lepida* Gould. The latter was shown by Baker (1, p. 140), to be a misidentification.

The next two papers to mention the lake (12, 14) merely confirm the finds already made and add no new species to the list.

In another paper by Latchford and Poirier (13) two *Sphaeriids* are added to the list, the first from McGoey Lake and the other from Meach: *Sphaerium simile* (Say) and *Musculium rosaceum* Prime. The seven other papers in the reference list that deal with the lake, add no new species to the list.

The writer's 1932 collection added five more species to the list: *Helisoma campanulatum wisconsinense* (Winslow), *Helisoma trivolvis pilsbryi* (F.C.B.), *Campeloma* cf *decisum* (Say), *Pseudosuccinea columella* (Say), and *Succinea retusa* (Lea). The 1934 collections added five more: *Pisidium* sp., *Gyraulus parvus* (Say), *Physa gyrina* Say, *Ferrissia parallela* (Say) and *Amnicola ?limosa porata* (Say). This brings the number of species to seventeen, as follows:—

Musculium rosaceum Prime
Pisidium sp.
Anodonta marginata Say
Elliptio complanatus (Dillwyn)
Lymnaea stagnalis lillianae F. C. Baker
Bulimnaea megasoma (Say)
Pseudosuccinea columella (Say)
Gyraulus parvus (Say)
Helisoma trivolvis pilsbryi (F. C. Baker)
Helisoma campanulatum wisconsinense (Winslow)
Helisoma anceps latchfordi (Pilsbry)
Physa parkeri latchfordi F. C. Baker
Physa gyrina Say
Ferrissia parallela (Say)
Amnicola ?limosa porata (Say)
Campeloma cf *decisum* (Say)
Succinea retusa (Lea)

Discussion of the List

This assemblage of species shows a typically northern molluscan fauna, very much like that of other Gatineau Valley lakes in the abundance of species like *Lymnaea stagnalis*, *Campeloma decisum*, *Ferrissia parallela*, *Pseudosuccinea columella*, etc. With these other lakes it shares a scarcity of representatives of the genus *Stagnicola*, the only one to produce these in abunddance being Chilcott Lake, a few miles north of Meach, where *S. laurentiana* Latchford is as common as *Lymnaea stagnalis* in other lakes. Especially notable is the absence of the *S. emarginata* group of which Baker (2, p. 234) says: "The habitat is normally in lakes or large rivers, often in situations where there is violent wave action." The species is present in the Rideau River; the lake presents the right kind of habitat, yet no *Stagnicola* is to be found there.

But Meach Lake resembles other Gatineau Valley lakes in another respect, the tendency to produce unusual variations. So far as is known the nearest locality for *Helisoma trivolvis pilsbryi* is Oneida Lake, in New York State; the nearest *recorded* locality for *H. anceps latchfordi* is Brome Lake, Quebec, but these may turn out to be the nearly related variety *portagense* described from Maine. *Physa parkeri latchfordi* has not been recorded for any locality between Michigan and Meach Lake.

Another remarkable feature is the absence of Naiades of the genera *Lampsilis* and *Alasmidonta* which are common, the one in Gauvreau, Grant and Blue Sea Lakes and the other in Taylor and Bernard Lakes.

Systematic Account of the Species

The ecological data which are summarized in the tables are assembled here under each species and discussed in detail. Certain varieties have been differentiated which did not appear in previous work and a discussion of the characters which led to this differentiation is given.

Musculium rosaceum Prime: This species is reported by Latchford and Poirier (13). One dead specimen of a *Musculium* was collected on sand mixed with some clay at Station 12 but no live specimens were obtained anywhere in the lake. While it is very probable that this specimen belongs to the species *rosaceum* the group is so difficult that a definite identification is best left to a specialist.

Pisidium sp.: At the same station one specimen of a *Pisidium*, also dead, was obtained. Live specimens, perhaps of the same species, were fairly frequent in the creek emptying into Tilley Bay; dead specimens were found as far as twenty feet out in the bay, but only in the immediate vicinity of the mouth of this creek.

Anodonta marginata Say: Common in mud habitat, group B. In August 1933 gravid females of this species were collected but when examined for glochidia they were found to contain only eggs. The same condition obtained in gravid females collected in September 1934. Baker (2, p. 166) found

"none gravid in July and August" and of the breeding season says: "probably similar to that of *Anodonta grandis*", that is, glochidia discharged very early. Since the glochidia were not mature in September it is unlikely that they are discharged (in *A. marginata*) until the Spring.

Elliptio complanatus (Dillwyn): This species is rare in the rock habitat, commoner in sand and entirely absent from the mud. The specimens are very compressed and of small size. Umbones were eroded in all specimens examined. No glochidia observed.

Lymnaea stagnalis lillianae F. C. Baker: Found in all habitats; thrives on sand and rock, but rare on mud. Material from Meach Lake was included in a supplement to the Ottawa list published recently by the writer (5, p. 34). The aperture-spire ratio is fairly constant, the aperture being longer than the spire in all but two specimens, both of which were from mud in protected bays. The dwarfed specimens are discussed below in the section on the dwarf fauna.

Bulimnaea megasoma (Say): The only specimens found by the writer came from a rock habitat (Station 17) and were collected in 1933. In 1934 the species could not be found anywhere in the lake. Many of the papers dealing with the mollusca of Meach Lake record *Bulimnaea megasoma*. Small and Symes (15, p. 57) state that the species was first found there "by Mr. Latchford in September 1880, and a good series was secured during the past season (1882)." Poirier mentions it again in the next year (14, p. 74) and with Latchford in 1885 records it for McGoey Lake. So far no specific locality in Meach Lake had been given. In the next two papers in which he mentions the species Latchford gives first "in a bay near Mr. Tilley's cottage, Meach Lake" and then, more specifically: "in a sheltered bay two hundred yards north of the Tilley cottage." Exactly what bay was meant cannot be ascertained definitely but if the distance is stretched a bit Mud Bay may have been meant. Specimens were plentiful since a good series was secured.

In 1934 Mud Bay was carefully searched, but no specimens were to be found. The same applies to Station 17 where specimens were obtained in 1933. It seems that *B. megasoma* has been losing ground in Meach Lake until now it is almost certainly extinct. A particularly careful search was made of all likely stations in the lake itself, in the inlet and in McGoey Lake, without success.

The causes of this extinction can only be guessed at, but the following may have had some effect: (a) raising of the level of the lake by the dam at the outlet; (b) the unusually severe winter of 1933 which came on very suddenly at the end of October and lingered into April; (c) pollution of the lake by sewage. The last is extremely unlikely since very little sewage is emptied into the lake and the water always appeared clear and clean.

Pseudosuccinea columella (Say): Abundant on water lily leaves, mud habitat. The specimens collected were small as a general rule, the largest being 16 mm. in length.

Gyraulus parvus (Say): Rare on water lily leaves, mud habitat. The species was determined by Mr. F. C. Baker.

Helisoma trivolvis pilsbryi F. C. Baker: Common on water lily leaves in the mud habitat, rare in the rock habitat, none found on sand. Adult specimens are consistently larger than the variety found in the Ottawa River, which is not quite typical according to Mr. Baker. In all the specimens collected the inferior carina is absent, the nuclear whorls regularly rounded below and with only very minute revolving lines. This character alone would distinguish the specimens from typical *trivolvis* and *infracarinatum*, both of which have a well-marked carina on the umbilical side of the nuclear whorls in the majority of cases, rare specimens having faint revolving lines. This record of *pilsbryi* is the first for the Ottawa district. The specimens were identified by Mr. F. C. Baker. It is probably present in Taylor and Philip lakes but so far no specimens have been collected in either lake.

Helisoma campanulatum wisconsinense (Winslow): Common on water lily leaves, mud habitat, and frequent on sand and rock. This species seems adapted to thrive in all three habitats. The Meach Lake specimens are placed in this variety on the strength of their axial height and slightly carinate whorls. The spire is not as elevated above the last whorl as in specimens from Tomahawk Lake, Oneida County, Wisconsin, nor are the whorls as strongly carinate. But the same variation may be seen in specimens of *wisconsinense* from Blue Sea Lake, Quebec, considered by Miss Winslow to belong to this variety.

Helisoma anceps latchfordi (Pilsbry): It seems that a combination of shallow water and sand bottom is necessary for the well-being of this variety. Occasional specimens were found on rock and mud, but only a few in each case. As may be seen from the list of sand habitats below, whenever the water deepens to more than three feet *latchfordi* disappears, to reappear again when it becomes shallower.

Lake specimens of the variety are fairly constant in height, width of umbilicus, strong carination and shape of aperture. The spiral lines, which are very faint on the superior and inferior walls of the shell, tend to disappear entirely on the side of the whorl between the carinae. In any case, the spiral lines, when present, are so faint as to be indistinguishable except under a strong magnification. They appear as fine wrinkles between the vertical riblets, upon which they do not impinge. The importance of this character will appear when the fauna of Taylor Lake is discussed; the *latchfordi* from this lake have strong spiral lines which cut the riblets and are visible without the aid of a lens.

Physa parkeri latchfordi F. C. Baker: This variety thrives on both sand and rock. The assertion made by the writer that it was absent from the gravelly parts of the lake (4, p. 134) was due to insufficient collecting*. In the mud habitat this species is replaced by *P. gyrina* Say.

**In addition a printer's error made the passage read: "Both snails are absent from exposed gravelly parts of the lake which is covered with cat-tails." In the original this read: "Both snails are absent from exposed gravelly parts of the lake and from the bay at the west end which is covered with cat-tails."*

Specimens from Meach Lake sent to Dr. W. J. Clench were returned by him marked *Physa parkeri* Currier. While the two species are rather closely allied, still there are differences which enable one to separate them. In *latchfordi* the shell is thinner than in *parkeri*, the spire less flattened and the columella less twisted. Adult specimens of *parkeri* from the type locality are also much larger than any specimen from Meach Lake yet seen. These differences, while they are admittedly slight, are still sufficient to separate groups of specimens from the two type localities, and to preclude the dropping of *latchfordi* and its inclusion under *parkeri* as a direct synonym.

The Meach Lake form must be treated in one of two ways, either as an independent species or as a variety of *parkeri*.

Its treatment as a variety of *parkeri* would imply a derivation from that species and the presence at some time in the past of the species in localities intermediate between Michigan and Meach Lake. So far no such intermediates are known.

Its treatment as a species would imply derivation from the same stock, possibly now extinct, and parallel development in response to lake environment. It would not imply the presence of the species in intermediate localities.

The first alternative could be considered more judiciously if we knew more about the *Physae* of the intervening territory. So far *P. parkeri* has not been recorded anywhere in Ontario or New York but there are many lakes, at least in Ontario, where no collecting has ever been done. On the other hand the areas studied, such as the Toronto, Hamilton and Ottawa regions and the lakes of extreme western Ontario, have not yielded any specimens of *parkeri*. The species is so remarkable, both in size and appearance that any collector would rate it an extraordinary find and would not fail to record it in a local list.

The second alternative requires a greater knowledge of the genitalia and radula of the two forms and of the origin of both. But in either case the differences in the shell alone appear sufficient to retain the name *latchfordi*. In deference to Dr. Clench's greater experience the form is here treated as a variety or race of *parkeri* but the writer fails to see how it could be derived from that species. The hypothesis of parallel development from the same stock appears more probable and more in accord with the apparent absence of the species in intervening localities.

Physa gyrina Say: Found sparingly on water lily leaves, mud habitat. Specimens identified by Dr. Clench.

Ferrissia parallela (Say): Fairly common on water lily leaves, mud habitat. The shell is almost invisible on a wet leaf and must be searched for carefully if any quantity is to be obtained.

Amnicola ?limosa porata (Say): Fairly common on water lily leaves, mud habitat. Most of the specimens taken were immature but the globose form, slightly flattened spire whorls and widely open umbilicus place these specimens almost certainly in *limosa porata*.

Campeloma cf. *decisum* (Say): This species is found in sand only. The shells are thin as in the *decisum-milesii* group, resembling the former more than the latter. As a large series of specimens both dry and in alcohol were collected, a study of the characters used by Baker (2, p. 57) in differentiating the species could be made. All the specimens examined were females, most of them with embryonic young, others with eggs only.

The young show a spire with sunken apical whorls as figured by Baker (2, p. 77 and Fig. 33) for *decisum*. There is considerable variation in the erosion of the spire in the adult, specimens varying all the way from those having the spire intact to some in which all but the last two whorls are worn off and which have in addition other worn spots unconnected with the spiral erosion.

Three radulae of this Campeloma were mounted and measured. The central tooth is 30μ wide as compared with 50μ for *decisum* and 40μ for *milesii* as given by Baker (2, p. 57). On this evidence, then, this form approaches *decisum* in the character of the embryonic whorls but is nearer *milesii* in the size of the central tooth.

The specimens are therefore placed doubtfully in *decisum* but it is the writer's belief that they will eventually be recognized as a distinct variety or species. However, since the classification of the group is far from satisfactory, the naming of this form must be delayed until more is known about the species of *Campeloma* already described.

Succinea retusa (Lea): Rare, on water lily leaves, mud habitat. Specimens of both this species and *P. columella* were dissected to make sure of the identification. Both species are present in the same habitat, sometimes one of each on the same leaf but only in one station (No. 26) was *S. retusa* found.

Detailed Description of the Habitats

That part of the shore of Meach Lake which is included within the ten-foot contour below water level may be divided into three main groups according to the character of the bottom. On the whole these groups are fairly distinct but may grade into each other. They may be defined as follows:

1. *Rock:* Varying from sheer rock wall or precipitous rocky shores to boulders interspersed with coarse gravel. The rocks are covered with green filamentous algae in a mat one-eighth to three-quarters of an inch thick. The water usually deepens quickly and vegetation is scarce.

2. *Sand:* Fine sand, with flakes of mica and in spots a little clay. The water usually deepens slowly. This type of bottom is found mostly in small protected bays and is most extensive at the southeast end of the lake.

3. *Mud:* Sticky, soft blackish-brown mud in a layer at least four feet deep in places, supporting an abundant and varied assemblage of water plants.

Each habitat is treated in more detail below.

Fauna of the Rock Habitat

Twenty-four stations of this type were studied, only two of which had no molluscan fauna. The species present are indicated in Table I. From this table it will be seen that the characteristic species of this habitat are *Lymnaea stagnalis lillianae* and *Physa parkeri latchfordi* with *Helisoma campanulatum wisconsinense* a poor third while the other species are represented by occasional specimens only.

Stations 53 and 54, where the rock rises perpendicularly out of the water and is exposed to the full force of the waves, are entirely devoid of shells.

In Stations 37, 39 and 40 where the rocky bottom was strewn with patches of clay and sand, shells were scarcer than on unmixed sand or rock bottom.

The two occurrences of *H. anceps latchfordi* are negligible as in both cases specimens were very scarce. At Station 8 only one live and two dead specimens were collected and at Station 31 only one specimen was seen.

An anomalous occurrence is that of *B. megasoma* on the rocky shore of the island at Station 17 in 1932. In 1934 every foot of this locality was examined but no *B. megasoma* found.

TABLE I

FAUNA OF THE ROCK HABITAT

Species	Stations											
	1	4	8	13	14	17	23	30	31	32	35	37
L. stagnalis lillianae	c	c	c	c	c	c	c	c	c	c	c	r
Physa parkeri latchfordi	c	c	c	c	c	c	c	c	c	c	c	r
H. c. wisconsinense		r	r	r	c	c		c	c	c		
H. a. latchfordi			r						r			
H. t. pilsbryi						r						
Elliptio complanatus						r						
*Bulimnaea megasoma**						r						

	Stations											
	39	40	42	47	49	50	51	53	54	55	57	58
L. stagnalis lillianae	r	r	c	c	c	c	c			c	c	c
Physa parkeri latchfordi	r	r	c	c	c	c	c			c	c	c
H. c. wisconsinense												
H. a. latchfordi												
H. t. pilsbryi												
Elliptio complanatus												
*Bulimnaea megasoma**												

*1932 only.

Fauna of the Sand Habitat

Eighteen stations of this type were examined, which varied greatly in character. The distribution of species is shown in Table II. *Lymnaea stagnalis lillianae* and *Physa parkeri latchfordi* are abundant, as in the rock habitat. Where the water is shallow (0–3 ft.) *Helisoma anceps latchfordi* is

TABLE II

FAUNA OF THE SAND HABITAT

	2*	5*	6	7*	9	10*	12*	22*	29
E. complanatus	x								x
Pisidium sp.	x						x		
L. s lillianae	x	x	x	x	x	x	x	x	x
P. p. latchfordi	x	x	x	x	x	x	x	x	
H. a. latchfordi	x	x		x		x	x	x	
A. l. porata							x		
C. ?decisum	x						x		
Musculium sp.							x		
H. c. wisconsinense	x	x	x	x	x	x			

	33*	34	36	38	41	43	44*	45	52
E. complanatus									
Pisidium sp.									
L. s. lillianae	x	x	x	x	x	x	x	x	x
P. p. latchfordi	x	x	x	x	x	x	x	x	
H. a. latchfordi	x						x		
A. l. porata									
C. ?decisum	x	x							
Musculium sp.									
H. c. wisconsinense									

**Water shallow (0–3 ft.); others, water deep (3–10 ft.).*

found abundantly. *Campeloma* cf *decisum* is probably more abundant than the table indicates, for owing to its burrowing habits it is harder to find. The other species are represented only by occasional specimens.

Fauna of the Mud Habitat

Nine stations of this type were examined. These may be divided into two groups:

A: Occasional small areas of mud, without plentiful vegetation (Stations 3, 14, 25 and 28).

B: Large areas, with plentiful vegetation (Stations 11, 11a, 16, 21 and 26).

The fauna of group A is very much like that of the rock bottom, the same two characteristic species being present. That of group B is entirely different. In the shallow bays of the lake, the bottom is covered with a dark brown, sticky, soft mud which supports a large number of water plants: white water lily *Nymphaea odorata* Ait., yellow water lily *Nymphozanthus advena* (Ait.) Fern., water milfoil *Myriophyllum alterniflorum* D.C., bulrushes *Typha latifolia* L. and perhaps also *T. angustifolia* L., pickerel-weed *Pontederia cordata* L., water-weed *Elodea canadensis* Michx.

On these weeds, as well as on the mud bottom, a large number of species were found. Their distribution is shown by stations in Table III.

TABLE III

FAUNA OF THE MUD HABITAT

	3	11	11a	14	16	21	25	26	28
Anodonta marginata		x(1)	x		x	x		x	
Gyraulus parvus			x		x	x		x	
A. ?limosa porata			x		x	x		x	
Ferrissia parallela			x		x	x		x	
H. c. wisconsinense			x		x	x		x	
H. t. pilsbryi			x		x	x		x	
Ph. gyrina			x		x	x		x	
P. columella			x		x	x		x	
L. s. lilliianae				x	x(2)	x(2)	x		x
Ph. p. latchfordi	x			x			x		x
H. a. latchfordi	x								
Succinea retusa								x	

(1) *Other species present but only A. marginata taken.*
(2) *Approaching var. jugularis; one specimen at each locality.* *See note page 50.*

Lymnaea stagnalis is present but very scarce, and the only two specimens taken have an elongated spire, approaching that of variety *jugularis*, a response to a quiet water environment. *Physa gyrina* here replaces *P. parkeri latchfordi*. In the mud itself *Anodonta marginata* is common but it was on the underside of water lily leaves that the greatest variety of species was taken. On these the following were found: *Gyraulus parvus* (Say), *Amnicola ?limosa porata* (Say), *Ferrissia parallela* (Say), *Helisoma campanulatum wisconsinense* (Winslow), *Helisoma trivolvis pilsbryi* (F.C.B.), *Physa gyrina* Say and *Pseudosuccinea columella* (Say). The number of individuals on a leaf varied, however. Specimens were more abundant on the large, rounded leaves of the white water lily than on the narrower, pointed ones of the yellow water lily. Leaves in an advanced state of decay were devoid of specimens, as were also the healthy, green leaves. The preferred habitat seemed to be those leaves which were just turning yellow.

Bulimnaea megasoma (Say) should live on the mud, in shallow water. The conditions in some places, especially at Stations 11, 11a and 21 are exactly similar to those in Taylor Lake where the species is abundant, yet no specimens were found on the mud anywhere in Meach Lake.

Fauna of the Inlets and Outlet

For purposes of comparison the following three faunules are included here. The fauna of McGoey Lake is essentially the same as that of Meach and so is not considered further here. The fauna of the inlet, of the small creeks flowing into the lake, and of the outlet, show the effect of a different environment on the same species.

Dwarf fauna: At the outlet of McGoey Lake, Station 61, the water rushes over an exposure of granite on which some very peculiar specimens were collected. They belong to two species only, *Lymnaea stagnalis* and *Physa*

?parkeri latchfordi. It seems that this particular combination of fast running water and rock bottom is unfavorable to molluscan life and that those species which are able to live there at all can only grow a shell smaller in all dimensions than those of the lake proper. Table IV shows a comparison of specimens of the dwarf fauna with lake specimens having the same number of whorls.

TABLE IV

COMPARISON OF MEASUREMENTS, DWARF FAUNA AND LAKE FAUNA

Station	No. of whorls	Length, mm.	Width, mm.	Ap. length, mm.
Lymnaea stagnalis lillianae				
61	4½	23	13.5	13.5
23	4½	34	18	19
61	5	20.5	10.5	12
61	5	21	11	12
61	5	24	14	14.5
61	5	24	14.5	13.5
61	5	25.5	14	15
61	5	25.5	14.5	15
61	5	26	15	14.5
61	5	28.5	16	16.5
61	5	30	17	17
16	5	33	19	22
23	5	39.5	21	23
23	5	39.5	23	23
16	5	40	20	24
61	5½	27	15	16
16	5½	45.5	24	25.5
Physa parkeri latchfordi				
61	4½	15	9.5	
8	4½	19.5	12	
61	5	15.5	11	
61	5	15.5	10	
23	5	20	14.5	
10	5	20	15	
8	5	20.5	14	
8	5	21	14	
61	5½	14	10.5	
10	5½	25	18	

From the table it will be seen that the specimens of *Lymnaea stagnalis* must be put under the variety *lillianae* since in every case the aperture is longer than the spire.

The *Physa* is doubtfully referred to *latchfordi* rather than *gyrina* since some of the specimens have a slight shoulder.

Fauna of the Inlet

In the inlet the following species were collected: *Physa parkeri latchfordi* F.C.B., *Helisoma anceps ?latchfordi* (Pils.), *H. campanulatum wisconsinense* (Winslow), *Amnicola* sp., *Elliptio complanatus* (Dillw.). The *Helisoma anceps* are uniformly smaller than those from the lake but otherwise similar. The same may be said of the *Physa* and *Helisoma campanulatum wisconsinense*.

Fauna of Tilley Creek

Tilley Creek, emptying into Tilley Bay (Station 2) furnished a few specimens of an unidentified *Pisidium*. The water of the creek is much colder than that of the lake and remains so for about 20 ft. after it joins the lake. In this narrow band of cold water *Pisidia* were found sparingly but in the warmer water on each side only dead specimens could be found.

TABLE V

OCCURRENCE OF THE SPECIES BY HABITATS

	Rock	Sand	Mud	Dwarf fauna	Inlet	Tilley Creek
Musculium rosaceum		dr				
Pisidium sp.		dr				c
Anodonta marginata			c			
E. complanatus	r	r			r	
L. s. lillianae	c	c	r	c		
B. megasoma	r					
P. columella			c			
G. parvus			c			
H. t. pilsbryi	r		c			
H. c. wisconsinense		c	c		r	
H. a. latchfordi	r	c	r		r	
P. p. latchfordi	c	c	r	c	r	
P. gyrina			c			
F. parallela			c			
A. ?limosa porata		r	c		r	
Campeloma cf. *decisum*		c				
Succinea retusa			r			

r: *rare;* dr: *rare, dead specimens only;* c: *common.*

Problems Suggested

1. *Bulimnaea megasoma:* Since it is known that this species is present upstream from Meach, the lake should be carefully watched in 1935 and subsequent summers to see if it will reappear there. If so, its disappearance in 1934 can be interpreted only as a minor fluctuation; if not, then it can be concluded that conditions have become permanently unfavorable for that species.

2. *Dwarf fauna:* It would be interesting also to see whether the dwarf fauna will reappear in the summer of 1935. Dwarf specimens have been collected only once and the conditions which produced the dwarfing may have been temporary. Further collecting at Station 61 would settle this point.

3. *The Outlet:* Meach Creek, the outlet of Meach Lake, should be investigated thoroughly over the whole of its course to the Gatineau River. It is more than probable that the peculiar varieties present in the lake are carried into the creek and perhaps even into the Gatineau River; yet they have never been found in the river. An investigation of Meach Creek may throw some light on the disappearance of these varieties, or their modification into river forms.

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References

1. Baker, Frank C. Lymnaeidae of North and Middle America. Chicago Acad. Science, Spec. Pub. No. 3. 1911.
2. Baker, Frank C. Fresh-water Mollusca of Wisconsin. Part I, Gastropoda. Wisconsin Acad. Science Arts Letters, pp. i-vi, 1-495. 1928.
3. Heron, Gilbert. On the Land and Fresh-water Shells of the Ottawa. Trans. Ottawa Field-Nat. Club, I: 36-39. 1880.
4. La Rocque, A. Notes on *Helisoma latchfordi* Pils. and *Physa latchfordi* F. C. Baker. Can. Field-Nat. 47 : 134-135. October, 1933.
5. La Rocque, A. Mollusca of the Ottawa Region—Additions and Corrections. Can. Field-Nat. 49 : 33-34. February, 1935.
6. Latchford, F. R. Notes on the Ottawa Uniones. Trans. Ottawa Field-Nat. Club, I. 3 : 48. 1882.
7. Latchford, F. R. Report of the Conchological Branch. Trans. Ottawa Field-Nat. Club, 3 : 65. July-Aug., 1889.
8. Latchford, F. R. Conchology. Ott. Nat. 7 : 114-116, October, 1893.
9. Latchford, F. R. *Limnaea megasoma*. Ott. Nat. 20 : 172. 1906.
10. Latchford, F. R. Conchological notes. Ott. Nat. 25 : 68. 1911.
11. Latchford, F. R. Canadian Sphaeriidae. Can. Field-Nat. 35 : 68-70. April, 1921.
12. Latchford F. R. and Poirier, Pascal. Report of the Conchological Branch for 1883. Trans. Ottawa Field-Nat. Club, II (1) pp. 130-133. 1884.
13. Latchford, F. R. and Poirier, Pascal. Report of the Conchological Branch. Trans. Ottawa Field-Nat. Club, 7 : 350. 1885.
14. Poirier, Pascal. Report of the Conchological Branch for 1882. Trans. Ottawa Field-Nat. Club, 4 : 74. 1883.
15. Small, H. B. and Symes, P. B. Report of the Conchological Branch for 1882. Trans. Ott. Field-Nat. Club, I, 3 : 57.